University of Alberta

COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION: A HEALTH PERSPECTIVE

by

Steven Michael Probert

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Environmental Science
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ABSTRACT

The purpose of this study was to determine whether proximity to industrial air emissions results in increased residential exposure to volatile organic compounds (VOC).

The study hypothesis was tested by comparing the air quality in Sherwood Park, immediately adjacent to a major industrial area, to the air quality in St. Albert that is approximately 20 kilometers from this industrial area.

The research used a 'receptor oriented approach' to measure residential indoor and outdoor VOCs. The data collection used a passive sampling device with GC/MS analysis, and the completion of an environmental inventory questionnaire.

The results determined most indoor VOC levels to be significantly higher than outdoor levels ($\alpha = 0.05$). There were no significant differences observed for most VOC levels between the fall and winter seasons ($\alpha = 0.05$). There were no significant differences in indoor VOC levels between the two communities, but outdoor levels of benzene, toluene, ethylbenzene, xylene and 1,3,5-trimethylbenzene were significantly higher in St. Albert ($\alpha = 0.05$).

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TABLE OF CONTENTS

1.0 Introduction 1

1.1 Theme and Scope 1
1.2 General Problem Statement 1
1.3 Hypothesis 2

2.0 Background Information 3

2.1 Air Quality 3
2.2 History of Indoor Air Quality Science 4
2.3 Health Risk Assessment Concepts 5
2.4 Exposure Assessment 6
2.5 Volatile Organic Compounds (VOCs) 10
2.5.1 Types of VOCs 10
2.5.2 Sources of VOCs 11
2.5.3 Fate of VOCs 14
2.5.4 Adverse Health Effects of VOCs 16
2.5.5 Target VOCs for Current Research 19

3.0 Development of Research Objectives 22

4.0 Description of Study Area 23

5.0 Research Approval by the Health Research Ethics Board 27

6.0 Materials and Methods 29

6.1 Spatial Sampling Design 29
6.1.1 Selection of Target Communities 29
6.1.2 Selection of Dwelling Units 33
6.1.3 Participant Recruitment 36
6.1.4 Participant Consent 37
6.2 Temporal Sampling Design 38
6.2.1 Temporal Variation of VOCs 38
6.2.2 Participant Scheduling in Fall 40
6.2.3 Participant Scheduling in Winter 41

6.3 Air Sampling and Monitoring 41
6.3.1 Selection of Air Sampling Methodology 41
6.3.2 Theory of Passive Air Sampling Devices 45
6.3.3 The 3M OVM-3500 Passive Air Sampling Device 48
6.3.3.1 Description 48
6.3.3.2 Limitations 48
6.3.3.3 Validation 51
6.3.3.4 Field Procedure 53
6.3.3.5 Quality Assurance and Quality Control 54
6.3.4 Temperature and Relative Humidity Monitoring 56
6.4 Laboratory Desorption 57
6.4.1 Selection of Methodology 57
6.4.2 Methods 58
6.4.3 Quality Assurance and Quality Control 58
6.5 Laboratory Analysis 59
6.5.1 Selection of the Methodology 59
6.5.2 Methods 60
6.5.3 Quality Assurance and Quality Control 61
6.6 Microenvironmental Questionnaire 61
6.6.1 Purpose of Questionnaire 61
6.6.2 Limitations of Questionnaire 62
6.6.3 Development of Questionnaire 63
6.6.4 Field Procedures for Questionnaire 65

7.0 Results and Discussion 66

7.1 Sampling Design 66
7.2 Air Monitoring 67
7.3 Treatment of Censored Data 68
7.4 Data Analysis 72
7.4.1 Indoor to Outdoor Comparison of VOC Levels 73
7.4.2 Seasonal Comparison of VOC Levels 76
7.4.3 Community Comparison of VOC Levels 79
7.4.4 Residential VOC Levels 81
7.4.5 International Comparison of Indoor VOC Levels 84
7.5 Quality Assurance and Quality Control (QA/QC) 85
7.5.1 Air Sampling QA/QC 85
7.5.2 Laboratory Desorption QA/QC 86
7.5.3 Laboratory Analysis QA/QC 87

8.0 Conclusions 90

9.0 Recommendations 92

10.0 References 93

11.0 Appendices **103**

Appendix 1	HREB Request for Ethics Review	104
Appendix 2	HREB Health Research Ethics Approval	117
Appendix 3	Notice Of Administrative Approval	120
Appendix 4	Map of Sherwood Park Strata	121
Appendix 5	Map of St. Albert Strata	122
Appendix 6	Sampling Distribution Estimates and Results	123
Appendix 7	Recruitment Pamphlet	127
Appendix 8	Field Recruitment Protocol	128
Appendix 9	Recruitment Campaign Field Procedure	129
Appendix 10	Introduction Letter	130
Appendix 11	Information Sheet	131
Appendix 12	Participant Consent Form	133
Appendix 13	Fall Monthly Scheduling Templates	135
Appendix 14	Winter Monthly Scheduling Templates	136
Appendix 15a	Fall Daily Scheduling Template	137
Appendix 15b	Winter Daily Scheduling Template	138
Appendix 16	Field Air Sampling Procedures:	139
16a	Air Sampling Equipment	139
16b	Indoor Air Sampling Procedure	140
16c	Outdoor Air Sampling Procedure	142
Appendix 17	Field Air Sampling QA/QC	144
Appendix 18	Laboratory Desorption:	145
18a	Laboratory Equipment	145
18b	Laboratory Equipment Cleaning Procedures	147
18c	Laboratory Desorption Procedure	148
Appendix 19	Laboratory Desorption QA/QC Procedures:	149
19a	Carbon Disulfide Purification Procedure	149
19b	Calibration of Hamilton Syringe or Micropipette	150
19c	Determination of Desorption Efficiency	151

Appendix 20		Microenvironmental Survey Questionnaires:	152
	1.	Questionnaire: Household Characteristics (Fall)	153
	2.	Questionnaire: Household Activities (Fall)	161
	3.	Winter Questionnaire: Changes to Household Characteristics and Household Activities	165
Appendix 21		Questionnaire Field Procedures	171
Appendix 22		Field Data Log	172
Appendix 23		Meteorological Summary	178
Appendix 24		Volumetric Concentrations of Target VOCs	184
Appendix 25		Calculation Constants for the Determination of Ambient VOC Concentrations	195
Appendix 26		Data Distributions for Target Compounds	196
Appendix 27		Statistical Tests for Indoor-Outdoor Differences	201
Appendix 28		Statistical Tests for Fall-Winter Differences	203
Appendix 29		Statistical Tests of Variance	205
Appendix 30		Statistical Tests for Community Differences	206
Appendix 31		Summary of PSD Trip Blanks	208
Appendix 32		Summary of Indoor Sampling Precision	209
Appendix 33		Summary of Outdoor Sampling Precision	210
Appendix 34		Summary of the Carbon Disulfide Lab Blanks	211
Appendix 35		Summary of the Desorption Efficiency Test Results	211
Appendix 36		Summary of the Analytical Sensitivity	212
Appendix 37		Calibration Curve for 1,1,1-trichloroethane	212
Appendix 38		Summary of the Analytical Precision	213

LIST OF TABLES:

Table 1	Types of manmade VOC emissions.	11
Table 2	Selection matrix for target VOCs.	21
Table 3	Major industries within the Strathcona Industrial Corridor.	25
Table 4	Environmental sampling conditions.	67
Table 5	Proportion of samples below the detection limits.	69
Table 6	St. Albert residential VOC concentrations in fall.	74
Table 7	Sherwood Park residential VOC concentrations in fall.	74
Table 8	St. Albert residential VOC concentrations in winter.	75
Table 9	Sherwood Park residential VOC concentrations in winter.	75
Table 10	St. Albert residential indoor VOC concentrations.	77
Table 11	St. Albert residential outdoor VOC concentrations.	77
Table 12	Sherwood Park residential indoor VOC concentrations.	78
Table 13	Sherwood Park residential outdoor VOC concentrations.	78
Table 14	Residential indoor VOC concentrations.	79
Table 15	Residential outdoor VOC concentrations.	80
Table 16	St. Albert to Sherwood Park VOC concentration ratios.	81
Table 17	St. Albert and Sherwood Park residential indoor VOC concentrations.	82
Table 18	St. Albert and Sherwood Park residential outdoor VOC concentrations.	82
Table 19	Indoor to outdoor median residential VOC concentration ratios.	83
Table 20	International residential indoor VOC concentrations.	84

LIST OF FIGURES:

Figure 1	Map of Capital Health Region showing the proximity of St. Albert and Sherwood Park to industry.	26
Figure 2	Age distribution for Sherwood Park and St. Albert.	30
Figure 3	Dwelling types in Sherwood Park and St. Albert.	31
Figure 4	Employment rate for Sherwood Park and St. Albert.	32
Figure 5	Household income for Sherwood Park and St. Albert.	32
Figure 6	Schematic of 3M OVM-3500.	48
Figure 7	Schematic of outdoor mounting apparatuses.	54
Figure 8	Histogram of indoor/outdoor 1,1,1-trichloroethane data.	70

LIST OF EQUATIONS:

Equation 1	Determination of exposure.	8
Equation 2	Determination of diffusion flux.	46
Equation 3	Determination of mass sampling rate.	46
Equation 4	Determination of volumetric sampling rate.	47
Equation 5	Determination of ambient analyte concentration.	47
Equation 6	Determination of method detection limit.	61
Equation 7	Determination of limit of quantification.	61
Equation 8	Determination of ambient VOC concentration in air.	71
Equation 9	Determination of relative standard deviation.	85
Equation 10	Determination of relative percent difference.	88
Equation 11	Determination of recovery coefficient.	150

1.0 INTRODUCTION

1.1 Theme and Scope

This study measured volatile organic compounds (VOC) in ambient and indoor air in residential communities. The study addressed both indoor and outdoor air quality but its emphasis was on indoor air quality (IAQ). It attempted to establish whether a community with industrial air emissions has significantly greater exposure to VOCs than one that is not in close proximity to industrial emissions. The study was conducted in neighboring communities of the city of Edmonton, Alberta, Canada.

1.2 Problem Statement

Air pollution is an environmental and a health concern to government, industry and the public. This concern has resulted in the establishment of ambient air emission standards, air quality guidelines, use of air emission controls, use of alternative fuels and the adoption of "best available technology" philosophy by government and industry in an attempt to reduce air pollution. However, despite government and industry efforts to minimize air pollution, the public continues to demand better protection of their health. This study attempted to address health concerns of County of Strathcona residents, east of Edmonton, who live in close proximity to a heavy industrial area referred to as the Strathcona Industrial Corridor (SIC).

In 1996, Alberta Health conducted an epidemiological study "...at the request of Strathcona County Council, due to a concern that (the prevalence of) respiratory diseases, especially asthma, may be higher in their community"(Alberta Health, 1996). This study concluded that there was no evidence of appreciably higher rates of mortality (1984 to 1994) or hospital admissions (1990 to 1994) from asthma, bronchitis and emphysema in the County of Strathcona. However, this statement was than qualified with one stating that there was some evidence of a diagnostic shift "which must be considered when assessing population health" (Alberta Health, 1996).

The Alberta Health study appeared to have some inconsistencies with the results of other research. Dales et al. (1994) in a national study reported that the overall prevalence of asthma in Canada was 4.7%, as opposed to a prevalence of 9.9% in Fort

Saskatchewan and 14.4% in Sherwood Park (as cited in Hessel, 1996), both communities in the County of Strathcona. Although, Hessel discussed the possibility that this difference may be due to a diagnostic shift, he recommended further investigation of both industrial air emissions and residential indoor air quality as potential etiological sources (Hessel, 1996). Lastly, Health Canada (1998) found the prevalence of "current asthma" to be 13% in both the Capital Health Region, in the County of Strathcona and as the Canadian mean.

It is not clear whether the prevalence of asthma is higher within the County of Strathcona or community of Sherwood Park or if these results are due to some source of diagnostic shift bias. However, it would appear that the situation warrants further study. The purpose of this study was to evaluate the impact of the Strathcona Industrial Corridor upon residential air quality in Sherwood Park.

1.3 Hypothesis:

The hypothesis was that close proximity of Sherwood Park residences to a heavy industrial area with its associated VOC emissions significantly increases residential indoor VOC concentrations.

2.0 BACKGROUND INFORMATION

2.1 Air Quality

In industrialized nations, society congregates in urban centers, demands modern day comforts and conveniences, and expects a healthy living environment. These societal demands and expectations have resulted in a high density of motor vehicles and industry in urban centers where harm to human health and welfare is most likely to occur (Godish, 1988). Thus, air pollution would appear to be an inevitable concomitant of modern life and may be defined as (Canter, 1996):

> "the presence in the outdoor atmosphere of one or more contaminants or combinations thereof in such quantities and of such duration as may be or may tend to be injurious to human, plant, or animal life, or property or which unreasonably interferes with the comfortable enjoyment of life or property or the conduct of business."

The VOCs under investigation are considered to be air toxics, defined as follows (Alberta Environmental Protection (AEP), 1998):

> "A substance is an 'air toxic' substance if it enters the atmospheric environment in a quantity or concentration or under conditions (a) having or that may have an immediate or long term effect on the environment; (b) constituting or that may constitute a danger to the environment on which human life depends; or (c) constituting or that may constitute a danger in Alberta to human life or health."

However, despite the inevitability of air pollution in modern society humans continue to strive to obtain good air quality as reflected in the 'vision' of the Clean Air Strategic Alliance (CASA) in Alberta (CASA, 1996):

> "The air will be odourless, tasteless, look clear and have no measurable short- or long-term adverse effects on people, animals, or the environment."

It is important to recognize interrelationships of outdoor or ambient air quality (AAQ) and indoor air quality (IAQ). In AAQ, the focus is on impacts of air pollution on the ecosystem and it's indirect impacts on humans, as the direct effects of air pollution on vegetation and freshwater biota are proportionately much greater than those demonstrated on human health. (Guidotti, 1995). In IAQ, the focus is on the impacts of indoor air pollution on the indoor environment and subsequently on human health and well being.

The source of all indoor air is ultimately ambient air but the potential impact of AAQ on IAQ is dependent on many factors which are often neither evident nor anticipatory (Otson and Fellin, 1992). Thus, AAQ monitoring results may give one an overall impression of seasonal trends and short-term variations in air pollution but they do not accurately reflect IAQ.

2.2 The History of the Science of Indoor Air Quality

In about 1955, the implementation of Clean Air Legislation in the United States resulted in a general trend of improving AAQ since that time (Brooks and Davis, 1992). The U.S. Environmental Protection Agency (EPA) is required, under the Clean Air Act, to establish National Emission Standards for Hazardous Air Pollutants in order to protect public health (NAS, 1991). A modeling approach is used to establish these standards making several assumptions. The model assumes that sources emitting the greatest quantities result in the greatest exposures and that the further one moved from traditional point sources, the lower the resulting exposure. However, more recent research has demonstrated that these assumptions are incorrect for many air pollutants (NAS, 1991). There is now a large body of evidence indicating that indoor air may be more seriously polluted than ambient air in many large industrialized centers, and that personal activities may have a significant influence on IAQ (NAS, 1991; Calgary Health Services, 1993).

In the 1970s, as AAQ continued to improve, the relatively new concern over IAQ became an important public health issue possibly through a series of historical events (Brooks and Davis, 1992). The combination of more indoor sources of air pollution and tighter buildings resulted in an overall deterioration of IAQ. After World War II, synthetic building materials and furnishings were used more frequently. In the 1970s, the energy conservation movement resulted in 'airtight' buildings with more efficient heating, ventilation and air conditioning systems. The information technology boom resulting in the home office equipped with computers, printers and fax machines. Scientific advances over the past two decades have also advanced the science of IAQ. Instrumentation has allowed the detection of increasingly lower levels of chemical compounds allowing one to observe previously 'undetectable' indoor air pollutants. Lastly, medical research

reports an ability to demonstrate a correlation between chronic health problems and long-term exposure to low levels of indoor air pollutants (Brooks and Davis, 1992).

2.3 Health Risk Assessment Concepts

Traditionally, environmental regulatory agencies have measured and monitored pollutants in geophysical carrier media (i.e. outdoor air, surface water, ground water and soil) but they have not measured actual human population exposure. In the late 1960s to the mid-1970s, research discovered that human 'exposure' to pollutants varied significantly from quantities found in geophysical carrier media (Ott, 1990).

This section introduces a number of terms that are an integral part of health risk assessment and the contents of this report.

Concentration: "The concentration of an air pollutant is the amount of the material contained in a specified volume of air. …expressed in mass per volume units (e.g., $\mu g/m^3$) …(or) parts per million by volume (i.e., ppmv)" (Ryan and Lambert, 1991).

Exposure: "… contact at a boundary between a human and the Environment at a specific concentration for a specific interval of time; it is measured in units of concentration(s) multiplied by time (or time interval). … units of exposure are. concentration multiplied by time (e.g., $\mu g\ h/m^3$)" (NAS, 1991).

Dose: "…refers to that amount of chemical contaminant which crosses a boundary of the body and reaches the site of toxic action. … varies not only with the exposure profile but also with the physiological state of the individual" (Ryan and Lambert, 1991).

Microenvironments: "are specific situations of exposure, and as defined by Duan (1982), they are locations in space and time over which pollutant concentrations are assumed uniform and constant" (Ryan and Lambert, 1991).

A biologic impact pathway, described by Ryan and Lambert (1991), presents the health risk assessment concept starting from emission of a pollutant and ending with the adverse health effect. The air pollutant is discharged into the environment by its source, it is then transported through the environment where its fate is determined by physical and chemical processes which may include meteorological effects, topographical effects, ventilation effects, chemical transformations, adsorption and reemission. This results in the presence of the air pollutant in different environmental settings. The movements of humans in time and space through these different environments are determined by complex human behavior. Subsequently, this human behavior determines exposure and dose of the air pollutant. Lastly, an exposed individual's responsiveness or sensitivity to the air pollutant determines the adverse health effects (Ryan and Lambert, 1991).

Research dedicated to different parts of the biologic impact pathway has not been balanced (Ott, 1985). The sources, fate and transport and adverse health effects of air pollutants have received a lot of research attention. However, comparatively speaking the level of knowledge in the areas of exposure and dose are rudimentary. This seriously impairs one's ability to make an accurate health risk assessment. Further, sources can not be limited to the traditional smoke stack, sewer outfalls and toxic waste sites, but must also include the less traditional indoor sources (Ott, 1990). The current research focuses on IAQ and demonstrates its importance to human exposure relative to AAQ.

2.4 Exposure Assessment

In the 1980s, a total human exposure (THE) approach evolved which defines a three dimensional bubble around a person, and any pollutant contacting this bubble is considered exposure to that pollutant (Ott, 1990). The routes of exposure to this bubble may include ingestion, dermal absorption or inhalation. This approach changes the focus

of research from a source-oriented approach to a receptor-oriented approach (Ott, 1990), which is the approach used in this study.

A person may be exposed to VOCs through all routes of exposure but the primary route is inhalation resulting in 99% of one's total VOC exposure (Wallace, 1986a). There are specific compounds for which ingestion may be an equally important route including limonene in fruits (citrus scent) and disinfection byproducts such as chloroform in treated drinking water (Wallace, 1993). Weisel et al (1990) demonstrated that dermal absorption of chloroform during showering may be comparable to the quantities one inhales (as cited in Wallace, 1993). The operational limitations of the current study and the fact that inhalation is the major route of exposure resulted in its design only giving consideration to VOC concentrations in air.

The two general measurement methods for exposure are the direct and indirect approaches (Ott, 1985). The direct approach involves measuring the concentration of a pollutant that has been inhaled, ingested or dermally adsorbed. For inhalation, it may involve an individual wearing a personal exposure monitor (PEM) that allows the measurement of air pollutants in the receptor's breathing zone (Ryan and Lambert, 1991). This results in a direct measure of exposure that is usually coupled with a daily log of a person's activities and the locations visited. This may be the best approach when there is limited data available on a pollutant (Ott, 1985), but it is labor intensive and time consuming (Ryan and Lambert, 1991).

Another direct approach involves biological monitoring (NAS, 1991) where samples of blood, urine, sputum or expired breath may be taken and analyzed for biological markers (Ryan and Lambert, 1991). These biological markers refer to cellular, biochemical, or molecular measures that are indicative of exposure to environmental chemicals (NAS, 1991). Lioy (1990) promotes that measurements of biological markers be coupled with other exposure measurements. The biological markers could be used to identify exposed populations, and testing for these biological markers would create a database that would allow us to establish baseline values. Other research scientists have stated that biological markers could eventually become tools to evaluate when, why and how a person has been exposed (Lioy, 1990).

Biological monitoring is valuable for determining populations at risk and for conducting health effects research (Ryan and Lambert, 1991). However, Wallace (1988) stated that developing a relationship between the level of a biological marker and personal exposure is difficult because of the complex physiological and metabolic parameters involved in the uptake and elimination of a pollutant (as cited in Ryan and Lambert, 1991).

The indirect approach constructs an exposure profile based upon human activity patterns, and concentrations expected to occur in various locations. It requires an exposure model, representative human activity patterns and microenvironmental exposure monitoring (MEM) to establish concentrations in different settings (Ott, 1985). This approach can aid in identification of sub-populations, physical settings and human behaviors that increase personal exposure to hazardous pollutants (Ryan and Lambert, 1991). Further, the individual exposure profile may be combined to estimate the distribution of a total population's exposure with the upper tail possibly identifying high risk sub-populations (Ryan and Lambert, 1991). Indirect methods usually have a lower cost attached to them than the alternative direct methods (NAS, 1991). The current research employed an indirect approach by measuring residential VOC concentrations while reducing both the burden placed upon study participants and costs.

The general exposure model used in an indirect approach determines total exposure (E) to a pollutant by taking the sum of exposure from each microenvironment occupied over a specified time period (Ott, 1985). The mean pollutant concentration in each microenvironment is multiplied by the time spent in it to determine that portion of a person's exposure. This can be represented mathematically as (NAS, 1991):

$$E = \int_{t1}^{t2} C(t)dt, \qquad \textbf{Equation 1}$$

where C(t) is the relationship between concentration and time over a time interval of t_1 through t_2. The use of broad microenvironment classes may result in the loss of some variability but differences within a particular microenvironment are likely to be smaller than differences between different types of microenvironments (as cited in Ryan and Lambert, 1991). Generally, the models used in exposure assessment have a large

uncertainty and few have been validated (NAS, 1991). The indirect approach used in this study is widely employed but it is important to understand that the use of its results in exposure assessment yield an estimate of total exposure.

Air concentrations measured in microenvironments of concern are usually accompanied by data collection on parameters that may influence the results (NAS, 1991). This may include monitoring of physical or chemical parameters that influence exposure, or it may take the form of a questionnaire which collects information on physical properties of the environment, on simple categories of exposure, and/or on human activity patterns (NAS, 1991). The present research measured residential indoor VOC levels, monitored temperature and humidity as possible sources of sampling bias, and surveyed housing characteristics and indoor activities that may influence the indoor VOC concentrations.

Both the direct and indirect approaches of exposure assessment require time activity data but for different reasons. The PEM (direct) method requires this information in order to associate various activities and places with the level of exposure measured. The MEM (indirect) method requires this information to actually determine the exposure using the aforementioned model. Time activity data may be obtained through the maintenance of a diary, a twenty four-hour recall interview (Ryan and Lambert, 1991) or from a previous study's results.

Relatively recent recognition of the importance of the indoor environment to human exposure and the above data requirements initiated a number of studies which focused on human activity patterns (NAS, 1991). Ott (1988) stated that people spend more than 90% of their time indoors (i.e. home, work and in transit) and about 65 to 70% of their time in their homes (as cited in NAS, 1991). Robinson (1991) observed that Americans spend an average of 89% of their time indoors, 6% in a vehicle and 5% in an outdoor setting. A four city Canadian study that included Edmonton, Alberta, and sampled both children and adults, observed that urbanites spend on average 89% of their time indoors, 66% in their homes, 6% outdoors and 5% in transit (Leech et al., 1996). The large proportion of time that people spend in their homes is one of the major reasons for this study's focus on IAQ.

Recent research has found that missing exposure data can be obtained through the receptor oriented approach allowing completion of the health risk assessment model. In the future, a 'total human exposure' methodology may be used to develop a solid data base resulting in improvement of both health risk assessment and public policy. Only if the source and extent of exposure is ascertained can public health officials intervene to reduce exposure and public health risks through the most economical and efficient means (Ott, 1990).

2.5 Volatile Organic Compounds (VOC)

2.5.1 Types of VOCs

Volatile organic compound is a term used to describe hydrocarbons that exist in the gaseous state. Hydrocarbons or organic compounds are composed of carbon and hydrogen molecules that may occur in a gaseous, liquid or solid state. VOCs are compounds "...that exist as vapors over the normal range of air temperatures and pressures" (Spengler, 1991). They are a diverse group of compounds that include aromatic hydrocarbons, halogenated hydrocarbons, aldehydes, ketones, aliphatic hydrocarbons, alcohols, ethers and esters (Brooks and Davis, 1992).

In 1989, the U.S. EPA reported over 900 different chemical compounds have been found indoors (as cited in Otson and Fellin, 1992) with more than 300 of these compounds identified as VOCs at levels exceeding 1 part per billion by volume (ppbv) (Berglund et al., 1989; Calgary Health Services, 1993). VOCs exist in virtually all natural and synthetic materials with many applications including fuels, solvents, fragrances, biocides and flavor additives (Wallace, 1993). Previous studies have established some of these compounds as common indoor air pollutants based upon their frequency of occurrence at detectable levels. The most commonly measured VOCs are alkanes, alkylated benzenes and chlorinated hydrocarbons (Calgary Health Services, 1993). The current research targeted about 10% of the 300 VOCs detected to-date and one of the selection criteria for measurement was that the compound be a common indoor air pollutant.

2.5.2 Sources of VOCs

There are both natural and anthropogenic sources of VOCs responsible for the presence of VOCs in indoor and outdoor environments. The OECD (1990) in Europe reported that 31% of VOC emissions are natural and 69% are anthropogenic (as cited in Ciccioli, 1990). An inventory of manmade VOC emissions by the OECD (1990) reported that major sources of manmade VOCs are automobiles, power plants and industry (Table 1), which are all outdoor sources. The U.S EPA's national ambient data base shows only 10% of these VOCs exceed 1ppb including formaldehyde, phenol, benzene and acetaldehyde (Ciccioli, 1991).

Table 1: Types of manmade VOC emissions (after Ciccioli, 1990).

Type of Manmade Emission	Portion of Total Manmade Emissions
mobile sources	44.0%
power plants	37.2%
Industry	10.8%
residential/commercial heating	3.5%
Solvent use	0.4%
Miscellaneous	4.1%

Although, most VOCs released into the environment are from outdoor sources, it is indoor sources that account for most of our exposure. The ratio of indoor to outdoor VOC concentrations demonstrates this point, Yocom (1982) observed that this ratio is usually greater than one (as cited in Otson and Fellin, 1992). DeBortoli et al. (1986) observed a mean indoor total VOC concentration of 3 mg/m^3 to 0.4 mg/m^3 outdoors, and Lebret et al. (1986) observed that Dutch homes generally had higher indoor than outdoor VOC levels (as cited in Otson and Fellin, 1992).

In the 1980s, the U.S. EPA conducted the 'Total Exposure Assessment Methodology' (TEAM) studies in order to measure public exposure to twenty target VOCs in several areas of United States (Wallace, 1993). The studies measured the personal exposure of 800 participants over a 24-hour period with concurrent outdoor sampling in the participant's backyard. There were also some fixed indoor air samplers installed in living rooms of homes in 1987. The TEAM studies observed that personal exposures exceeded median outdoor concentrations by 2 to 5 times (Wallace et al, 1986a,

1986b and 1988) and that mean indoor levels were 2 to 10 times the outdoor levels (Wallace, 1991) for nearly all prevalent VOCs. Lastly, the TEAM studies looked at personal exposures to VOCs in non-industrial and heavily industrialized areas in the United States and observed no association, suggesting the major influence on exposure is the indoor VOC sources (Wallace et al., 1986a, 1986b and 1988). The fact that most personal exposure to VOCs occurs indoors was one of the major reasons for the present research to measure indoor VOC levels.

Indoor VOCs originate from building materials, building furnishings, appliances, office equipment and supplies, human activities and consumer products (Berglund et al., 1989; Wallace, 1991; Brooks and Davis, 1992; Otson and Fellin, 1992). Building materials and furnishings that may emit VOCs include adhesive, caulking compound, carpeting, ceiling tile, particle board, oriented strand board, drapery, floor and wall covering, upholstery, paint, stain, paint remover, solvent and varnish (Wallace, 1991; Otson and Fellin, 1992; Brooks and Davis, 1992).

Consumer products responsible for VOC emissions are continuously changing as are the consumer's patterns of usage. The research to-date has demonstrated that aerosol products, cleaning agents, polishing agents, hobby materials, air fresheners, mothballs, magazines, newspapers, drycleaned clothing and personal hygiene products all contribute to indoor VOC levels (Knoppel and Schauenburg, 1989; Wallace, 1991; Otson and Fellin, 1992 and Brooks and Davis, 1992). Ozkaynak (1987) observed that some of the most commonly emitted VOCs from consumer products are toluene, xylene and methylethylketone (as cited in Wallace, 1991 and 1993).

A variety of human activities have been associated with elevated indoor VOC levels and personal exposures. These activities include the performance of indoor renovations, redecorating, hobbies, clothes washing, dish washing, bathing and smoking (Wallace, 1991 and 1993; Otson and Fellin, 1992). U.S. EPA TEAM studies observed that maximum indoor VOC levels were often 100 to 1,000 times outdoor levels due to indoor human activities (Wallace, 1991). In German and American studies, an increased level of aromatic hydrocarbons was found to be associated with smokers' houses (Thomas et al., 1993; Otson and Fellin, 1992). Wallace (1991) found increased personal

exposure to VOCs was associated with carburetor cleaning, dish washing and bathroom deodorizer usage. Personal exposure to chlorinated VOCs was observed to be associated with bathing, clothes washing and dish washing in areas using chlorinated water supplies (Wallace, 1993). The use of mothballs resulted in an indoor to outdoor ratio of 20:1 for 1,4-dichlorobenzene and elevated personal exposure by about 60 times (Wallace, 1991). The pattern and duration of both human activities and consumer product use determines emission strength and subsequent indoor VOC levels. In 1989, Wallace concluded that the major sources of VOC exposure are small and close to the person (as cited in Otson and Fellin, 1992).

There are also certain housing characteristics that have been found to be associated with indoor VOC levels including gas appliances, fireplaces, and the heating, ventilation and air conditioning systems (Wallace, 1991, Otson and Fellin, 1992 and Brooks and Davis, 1992). There are also elevated VOC levels found to be associated with attached garages (Cohen et al., 1989 and Thomas et al., 1993). In large Dutch, German and American studies of 300 to 800 homes, it was observed that newer homes had higher VOC levels with those less than one year old to less than one month old having respective VOC levels that were several times to 100 times outdoor levels (Wallace, 1993).

Lastly, specific circumstances that may have a measurable impact on indoor VOC levels include microbial growth, nearby autobody shops, nearby print shops, nearby landfills, and houses built upon contaminated soil or groundwater (Kleist et al., 1989, Rivers et al., 1992; Otson and Fellin, 1992, and Wallace, 1991). In field studies, Miller et al. (1988) and McJilton et al. (1990) observed that foul odors and elevated VOC levels were associated with microbial growth (as cited in Rivers et al., 1992). In lab studies, common indoor bacterial and fungal strains were found to generate VOCs which are odor irritants including mercaptan, dimethyl disulfide, dimethyl trisulfide, trimethylamine and indole (Rivers et al., 1992). In a Dutch study (Kleist et al., 1989), it was observed that 7 of 77 houses built on contaminated soil had elevated VOC levels in the basement or crawlspace. Therefore, there is evidence demonstrating that nearby outdoor sources can result in elevated indoor VOC levels in more specific circumstances.

A literature review on sources of VOC emissions was important to this study for several reasons. It established that the major source of VOC emissions is usually outdoor sources. It also established that the major source of human VOC exposure is usually indoor VOC sources. These two points were the main justification for the present study's hypothesis. Lastly, it aided in the compilation of a list of major indoor VOC sources that was incorporated into a 'microenvironmental questionnaire' for the present research.

2.5.3 Fate of VOCs

The fate of indoor VOCs has received very little attention relative to source characterization and occurrence of VOCs due to complexity of indoor environments retarding research in this area (Otson and Fellin, 1992). The fate of a VOC is determined by its physicochemical properties and the conditions of the indoor environment. However, the effects of absorptive and transformation processes that determine this fate are poorly understood (Otson and Fellin, 1992).

Although, the fate of VOCs is not well understood a number of parameters have been observed to affect indoor air quality. Indoor VOC levels are largely determined by indoor source emission strengths that are dependent on the number, type and location of sources (Engineering Interface, 1988; NAS, 1991; Otson and Fellin, 1992). Indoor environmental conditions including temperature, relative humidity and ventilation rate have a considerable influence on both the emission rate and fate of VOCs (Engineering Interface Ltd., 1988; NAS, 1991; Otson and Fellin, 1992). A Canadian study of 200 homes observed ventilation rates ranging from 1.5 to 10.4 air changes per hour (Otson and Fellin, 1992). Cohen et al. (1989) observed that forced air heating, central air conditioning and the frequency of open windows were related to indoor VOC levels (as cited in Otson and Fellin, 1992). However, Wallace (1986a) inferred that a VOC source is a far stronger determinant of indoor VOC levels than air exchange rates after comparing the relatively small variability in the ventilation rate to VOC concentrations that may vary by 100 times. The present research determined sources of ventilation in the 'microenvironmental questionnaire' and measured indoor carbon dioxide levels during the investigators' visits as indicators of the ventilation rates.

It has been observed in numerous studies that new building materials and new building construction are often associated with higher VOC levels. This is clearly associated with some of the previously described common sources including carpeting, adhesives, paints, and particle board. The 'decay' of VOCs is dependent upon time, ambient conditions, and composition of the environment (Otson and Fellin, 1992). Jungers and Sheldon (1987) observed that indoor total VOC levels were significantly higher for the first four months after new building construction with substantial decreases over the subsequent 4 month period (as cited in Otson and Fellin, 1992). Cohen et al (1989) also observed that house age was related to indoor VOC levels (as cited in Otson and Fellin, 1992). The current research inquired about the age of the participant's homes in the 'microenvironmental questionnaire'.

The VOC adsorption and re-emission process has been identified in numerous studies (Berglund et al., 1989; Wallace, 1991; Guo et al., 1992). It is the result of elevated VOC emissions with subsequent adsorption by common building materials (sinks) followed by VOC re-emission from these sinks over a time period. The sinks may include clothes, carpets, ceiling tiles, and drywall and may result in elevated VOC levels for up to 40 days depending upon a compound's "decay factor" and the ambient conditions (Berglund et al., 1989; Wallace, 1991; Guo et al., 1992).

In a chamber study of seven year old building materials (Berglund et al., 1989), it was observed that 28 of 45 VOCs emitted appeared to have been adsorbed from other sources in the house and were than re-emitted in the chamber for 2 to 23 days. The other 17 VOCs appeared to be part of the original building material composition.

In a study of adsorption and re-emission in an unoccupied IAQ test house, the air concentration of ethylbenzene was elevated over a 72-hour period to C_{72}. After source removal, it took 10 hours for the concentration to drop to 75% C_{72}, 100 hours to drop to 1.4% C_{72} or 1.0 mg/m^3, and 1,000 hours (6 weeks) to drop to 0.02 mg/m^3 or 7 times the original background level of 0.003 mg/m^3 (Guo et al., 1992). The present research inquired within a 'microenvironmental questionnaire' about indoor activities around the time of VOC sampling that may have been associated with elevated indoor VOC emissions.

2.5.4 Adverse Health Effects of VOCs

In 1989, the U.S. EPA reported that indoor air pollution is a high human health risk and one of the greatest threats to public health of all environmental problems (Wallace, 1991; Brooks and Davis, 1992). Subsequently, the establishment of cause-and-effect relationships between indoor air pollutants and adverse health effects became a major challenge to investigators. However, few indoor air quality studies have met all of the scientific rigors and many different experimental approaches have made the comparison and combination of results difficult. This has resulted in a lot of cause-and-effect assumptions making both clinical diagnosis and public health management difficult (Brooks and Davis, 1992). In recognizing the uncertainty in a link between VOCs and adverse health effects, it is equally important to recognize that there is a large body of evidence demonstrating that very low VOC levels can cause both acute and chronic health effects. As one of the selection criteria, the current research required target VOCs to be identified as a potential health hazard.

Adverse health effects related to a pollutant are dependent upon a number of parameters including (Lebowitz, 1995):

- total exposure as a function of concentration and time,
- toxicity (dose response) of the pollutant and
- susceptibility of the individual host.

The more susceptible subpopulations include children, elderly persons, asthmatics, and persons with pre-existing health conditions such as reactive airway dysfunction syndrome or chronic obstructive pulmonary disease. These susceptible subpopulations have been observed to have more reactions to air pollution (Brooks and Davis, 1992; Lebowitz, 1995).

A urea foam formaldehyde insulation (UFFI) incident alerted health professionals to what has been referred to as 'tight building syndrome', 'building related illness', 'environmentally induced illness' or 'sick building syndrome' (Rogers, 1989). This incident was the result of a sudden wide use of UFFI in homes with a subsequent high incidence of sick building syndrome. This illness had a spectrum of symptoms including

headaches, nausea, lack of concentration, dizziness, lethargy, arrhythmia, flushing, laryngitis, irritability, depression, joint pain and extreme weakness (Rogers, 1989).

The UFFI incident was later recognized as 'chemical hypersensitivity' to a VOC named formaldehyde (Rogers, 1989). Since the UFFI incident a number of VOCs have been observed to induce chemical hypersensitivity including benzene, toluene, ethylbenzene, xylene, styrene, trichloroethylene, tetrachloroethylene, methane, phenol and aliphatic hydrocarbons (Rogers, 1989; Wallace, 1991). Chemical hypersensitivity demonstrates a tremendous individual susceptibility since different people with the same exposure can either be very ill or completely unaffected. These hypersensitive individuals can have severe reactions to very low VOC concentrations after a single sensitizing dose, a sequence of doses or after chronic exposure (Health Canada, 1995).

> "Although the cause of sick-building syndrome remains unknown, organic chemicals are highly suspect" (Wallace, 1991).

Exposure to occupational VOC concentrations, which are recognized to be higher than environmental concentrations, are reported to result in irritation and neural intoxication. Some of the compounds that are known to cause eye, nose and throat irritation include formaldehyde, acrolein and acetaldehyde (Ciccioli, 1991). It was reported that at high concentrations toluene, ethylbenzene, xylene and styrene can result in neurotoxic effects such as dizziness, headaches, and short-term memory loss (Wallace, 1991a).

There have been many epidemiological and toxicological studies demonstrating potential chronic health effects that include genotoxicity, mutagenicity, teratogenicity, carcinogenicity and a variety of systemic effects (Speijers, 1993). However, carcinogens appear to generate the most concern in relation to health effects associated with VOCs (Brooks and Davis, 1992). Known human carcinogens include benzene and vinyl chloride (Wallace, 1993). The possible or suspected human carcinogens include 1,3-butadiene, carbon tetrachloride, chloroform, 1,2-dibromoethane, 1,2-dichloroethane, formaldehyde, methylene chloride, 1,4-dichlorobenzene, tetrachloroethylene, styrene, trichloroethylene,

1,1,1-trichloroethane and vinylidene chloride (Brooks and Davis, 1992; Ciccioli, 1991; EPA, 1990; Kolstad, 1995; Liteplo and Meek, 1994; Newhook, 1994; Wallace, 1991b, 1993). Wallace (1991b) reported that the International Agency for Research on Cancer (IARC) classified aliphatic hydrocarbons as promoters or co-carcinogens.

EPA (1990) published a report which estimated upper-bound cancer risks associated with outdoor exposure to air toxics. Given the local public concern about outdoor industrial air emissions, it seemed prudent to give consideration to outdoor pollutants considered to be "...among the major contributors to cancer risk from air toxics..." (EPA, 1990). U.S. EPA policy makers in collaboration with scientists established a 'de minimus' or 'negligible lifetime risk' of developing cancer as one in a million. The U.S. EPA report looked at 'hazardous air pollutants' listed in the U.S. *Clean Air Act* and estimated the upper-bound risk from outdoor exposure to 17 of these pollutants to be at least 100 times the 'de minimus' level. These compounds included products of incomplete combustion, 1,3-butadiene, formaldehyde, benzene, chloroform, ethylene dibromide, gasoline vapors, ethylene dichloride and carbon tetrachloride (EPA, 1990).

The upper-bound lifetime risk from indoor and outdoor exposure to potential carcinogens has also been estimated by other studies and yielded similar results. Wallace (1991b) determined risk estimates that yielded 9 VOCs exceeding the 'de minimus' by a factor of 10 to 100 with 80 to 100% of the airborne risk being attributed to indoor air quality. These VOCs include benzene, 1,3-butadiene, carbon tetrachloride, chloroform, ethylene dibromide, formaldehyde, methylene chloride, 1,4-dichlorobenzene and vinylidene chloride. Ciccioli (1991) reported that the highest carcinogenic risks are associated with formaldehyde, 1,3-butadiene, benzene, methylene chloride, trichloroethylene and tetrachloroethylene. Although these risk estimates are valuable tools, it is important to understand that there are practical limitations in approaches used to estimate these upper-bound lifetime cancer risks. This study incorporated many of the aforementioned compounds demonstrating adverse health effects in its list of target VOCs.

2.5.5 Target VOCs for Current Research

Although, there have been more than 300 VOCs detected in indoor air (Berglund et al., 1989; Calgary Health Services, 1993), most studies only target a fraction of these. The Canadian study (Otson et al., 1992b) and some of the TEAM studies (Wallace et al., 1988) targeted 26 VOCs. The current research targeted specific VOCs by establishing selection criteria stating that a target VOC:

- should be a common indoor air pollutant,
- should be a potential health hazard, and
- should be measurable using the proposed methodology.

These selection criteria were used to ensure fulfillment of the research objectives from a health perspective. Common indoor air pollutants were considered those that a large proportion of society are routinely exposed to and are more likely to be able to be detected in indoor air. Compounds that were considered potential health hazards are those reported by others to result in deleterious health effects. Lastly, detectable and quantifiable compounds were considered those that may be evaluated by the proposed sampling and analytical methodology at typical environmental concentrations. The selection criteria were intended to maximize the likelihood of achieving the research objectives at a reasonable cost.

The selection process for target VOCs involved a comprehensive literature review compiling those that appeared to meet all selection criteria. The Canadian (Fellin and Otson, 1993; Otson and Fellin, 1992) and TEAM (Wallace et al., 1986a, 1986b and 1988) studies were excellent resources as they used similar selection criteria. The first criterion was met by selecting VOCs reported in other studies to be common indoor air pollutants (Table 2). The second criterion was met by selecting VOCs reported in other studies as either having adverse health effects or being classified as hazardous air pollutants (Table 2). The third criterion resulted in elimination of acrolein and formaldehyde as neither could be sampled using the passive sampling device (PSD) employed in this study (3M, 1998a). The third criterion also resulted in elimination of 1,3-butadiene, hexane, methyl ethyl ketone, methylene chloride, vinyl acetate, vinyl chloride and vinylidene chloride because they could not be analyzed using the analytical method (GC/MS) employed in

this study (Rose, 1998). There were some target compounds selected where it was unknown whether the first two selection criteria were met, but the third criterion was met. The final list of 25 target VOCs retained after evaluation of the selection criteria is presented in Table 2.

Table 2: Selection matrix for target VOCs.

VOLATILE ORGANIC COMPOUNDS	COMMON INDOORS[a] (Y/N/M/U)[e]	POTENTIAL HEALTH EFFECTS[b] (Y/N/U)	PSD[c] (Y/N)	GC/MS[d] (Y/N)
1,1-Dichloroethane	U	U	Y (10)	Y (12)
Chloroform	Y (1,2,6)	Y (3,7,8,13,14,17)	Y (10)	Y (12)
1,1,1-Trichloroethane	Y (1,6)	Y (4,14)	Y (10)	Y (12)
Carbon Tetrachloride	Y (1)	Y (3,4,7,8,14,17)	Y (10)	Y (12)
Benzene	Y (1,2)	Y (3,4,7,8,13,14,16,17,19)	Y (10)	Y (12)
Trichloroethylene	Y (1,2)	Y (3,4,8,13,16,19)	Y (10)	Y (12)
Toluene	Y (2,5,6)	Y (3,18,19)	Y (10)	Y (12)
1,1,2-Trichloroethane	U	Y (3,7)	Y (10)	Y (12)
Perchloroethylene	Y (1,2,5,6)	Y (3,4,7,8,11,13,16,19)	Y (10)	Y (12)
Chlorobenzene	Y (5)	Y (3,9)	Y (10)	Y (12)
Ethylbenzene	Y (1,2,5,6)	Y (3,18)	Y (10)	Y (12)
(m+p) Xylene	Y (1,2,5,6)	Y (3,18,19)	Y (10)	Y (12)
o-Xylene	Y (1,2,5,6)	Y (3,18,19)	Y (10)	Y (12)
Styrene	Y (1,2,6)	Y (3,14,18,20)	Y (10)	Y (12)
Bromoform	N (1)	Y (3,9)	Y (10)	Y (12)
Cumene	M (2)	Y (3)	Y (10)	Y (12)
1,1,2,2-Tetrachloroethane	N (1,2)	Y (3,7)	Y (10)	Y (12)
1,2,3-Trichloropropane	U	U	Y (10)	Y (12)
Hexachlorobutadiene	U	Y (3,9)	Y (10)	Y (12)
Naphthalene	M (2)	Y (3)	Y (10)	Y (12)
1,2-Dichloroethane	N (1,2)	Y (4,7,8,14)	Y (10)	Y (12)
1,3,5-Trimethylbenzene	M (2)	U	Y (10)	Y (12)
1,2,4-Trimethylbenzene	M (2)	U	Y (10)	Y (12)
1,3-Dichlorobenzene	Y (1); N(2)	Y (3,8)	Y (10)	Y (12)
1,4-Dichlorobenzene	Y (1,2)	Y (3,8,13,14,15)	Y (10)	Y (12)

a. Has the VOC been observed to be a common indoor air pollutant?
b. Has the VOC been reported as a potential health hazard?
c. May the VOC be sampled using the proposed PSD?
d. May the VOC be analyzed using GC/MS?
e. Y = yes, N = no, M = maybe and U = unknown

1. Wallace, 1986a
2. Fellin and Otson, 1993
3. EPA, 1990
4. AEP, 1998b
5. Brooks and Davis, 1992
6. Otson and Fellin, 1992
7. Bates, 1996
8. Environment Canada, 1999b
9. OCED, 1995
10. 3M, 1998b
11. Liteplo and Meek, 1994
12. Rose, 1998
13. Wallace, 1993
14. Wallace, 1991b
15. Wallace, 1990
16. Ciccioli, 1991
17. EPA, 1990
18. Wallace, 1991a
19. Rogers, 1989
20. Newhook, 1994

3.0 DEVELOPMENT OF RESEARCH OBJECTIVES

This section summarizes explicit rationale previously discussed supporting objectives of this research and clearly states these objectives. An accurate measure of human exposure should reflect the total quantity of a compound experienced in the environment (Ott, 1985). The U.S. EPA TEAM studies determined that 99% of exposure to VOCs occurs through inhalation of air and that indoor VOC levels were 2 to 20 times outdoor VOC levels (Wallace, 1986a and 1993). It was also determined that average Canadians spend approximately 66% of their time inside their home (Leech et al., 1996). Lastly, Wallace (1986a and 1993) reports that:

- major industry is responsible for less than 25% of VOC exposure,
- exposure correlates with indoor but not with outdoor VOC levels and
- indoor sources, usually at home, are responsible for most VOC exposure.

The current research objectives were to determine indoor and outdoor residential VOC levels in Sherwood Park and St. Albert, to determine if a difference in residential VOC levels exists between these communities as a result of proximity to industry, and to determine the residential indoor to outdoor VOC ratios in these communities.

4.0 DESCRIPTION OF STUDY AREA

The study was conducted in the vicinity of Edmonton, Alberta, Canada. The province of Alberta is the westernmost 'prairie province' in Canada and borders on the east side of the Rocky Mountains. The city of Edmonton is the capital of Alberta with a population of approximately 600,000 persons. This large urban center has two satellite communities bordering its city limits, the hamlet of Sherwood Park is on the east side and the city of St. Albert is on the northwest side. It also has a major industrial area, the Strathcona Industrial Corridor (SIC), located on the eastern perimeter of Edmonton and the western perimeter of Sherwood Park (Figure 1). The city of St. Albert is approximately 20 km northwest of this same industrial corridor. The entire study area is within the Capital Health Region and the Capital Health Authority is responsible for the provision of both acute and preventative health care within this region.

The satellite communities of Sherwood Park and St. Albert were the locations for the community sampling program aimed at testing the study hypothesis. They are both small, urban satellite communities with similar demographic characteristics, described further in section 6.0. They are less than 25 km apart resulting in an increased likelihood of their exposure to similar meteorological conditions.

The *National Pollutant Release Inventory* (NPRI) (Environment Canada, 1996) allows Canadians to access information on the pollutants released from industrial facilities to the environment. Facilities have been required to report to Environment Canada for the NPRI since 1993. The *Canadian Environmental Protection Act* (CEPA) requires facilities meeting the reporting criteria to submit, upon receiving notice from the Minister of the Environment, specified information on pollutants to Environment Canada. The following information discussing industrial on-site releases was obtained from *NPRI: Summary Report 1996*.

The NPRI report does not contain all sources and its contents must be considered in that context. It does not contain information on sources that do not meet reporting criteria including sources from sectors such as architectural surface coatings (e.g., paint), commercial and consumer solvent use, dry cleaning and solvent degreasing (Environment Canada, 1996). The case of tetrachloroethylene in Canada may be considered to

emphasize this point. The top ten industrial facilities in Canada with the highest on-site releases of tetrachloroethylene totaled 200 tonnes in 1996, whereas the drycleaning industry alone was responsible for the release of 4500 tonnes. The drycleaning industry does not report to Environment Canada for the NPRI report.

Celanese Canada Inc. is a 'chemical and chemical products industry' (Environment Canada, 1996) located in the SIC. This plant is responsible for the largest on-site industrial releases in Canada of acetone, acetaldehyde, methyl ethyl ketone and vinyl acetate. It is also among the top ten plants in Canada responsible for on-site industrial releases of formaldehyde and methanol (Environment Canada, 1996).

Alberta Envirofuels Inc. and AT Plastics Inc. are 'chemical and chemical products industries' (Environment Canada, 1996) also located within the SIC. These plants are among the top ten plants in Canada responsible for on-site industrial releases of vinyl acetate (AT Plastics) and methyl tert-butyl ether (Alberta Envirofuels) (Environment Canada, 1996).

Owens Corning Canada Inc., located within the SIC, is a 'mineral products industry'. It is also responsible for on-site industrial releases of formaldehyde (Environment Canada, 1996).

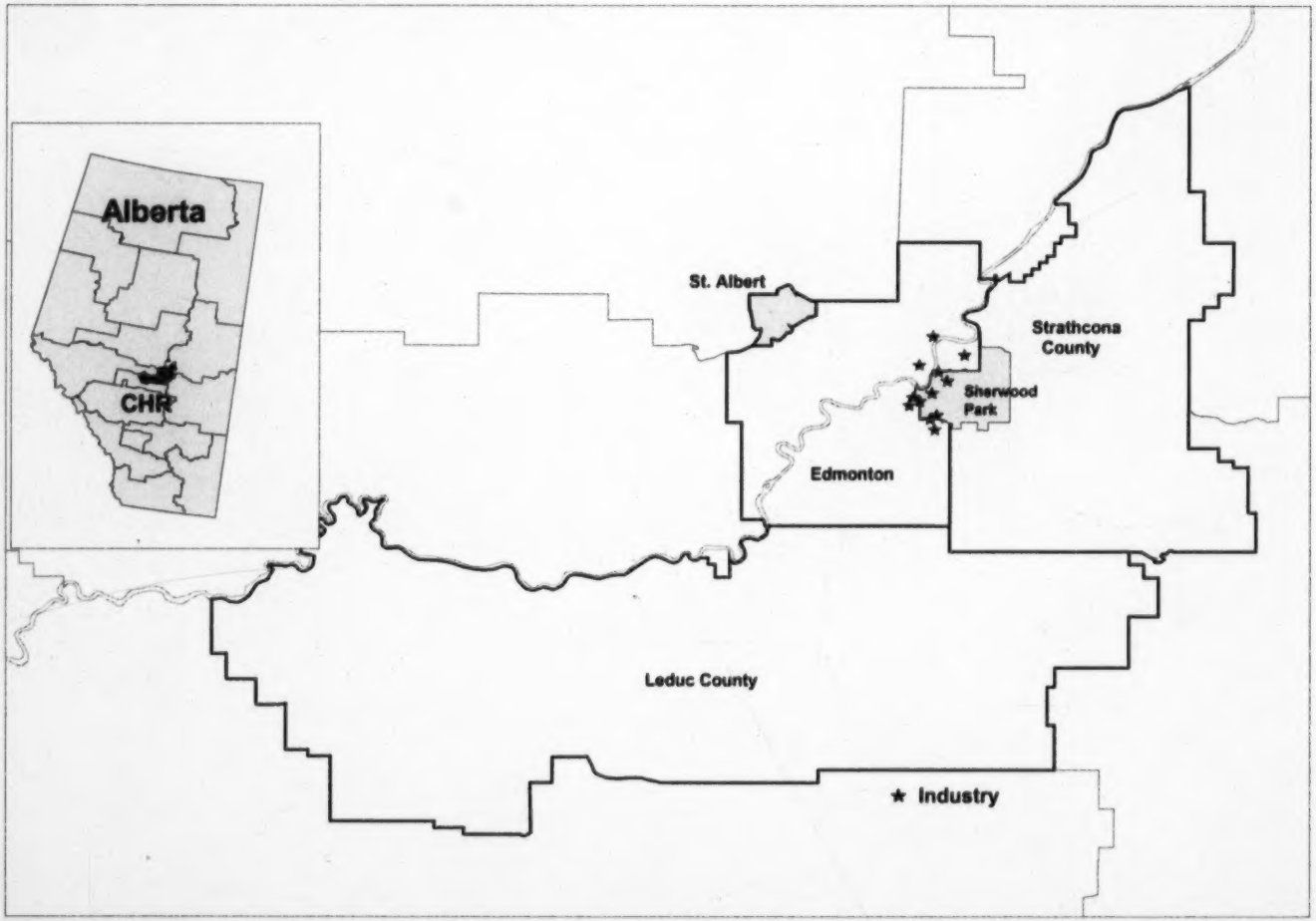
Imperial Oil and Petro-Canada, located within the SIC, are 'refined petroleum and coal products industries' (Environment Canada, 1996). Imperial Oil is among the top ten plants in Canada responsible for on-site industrial releases of cumene and napthalene. These plants are both also responsible for on-site industrial releases of benzene (Environment Canada, 1996).

The results of emission inventories have determined that industry is a leading source of VOC emissions to ambient air. The SIC is comprised of refined petroleum and coal products industries, chemical and chemical products industries and mineral products industries (Environment Canada, 1996). The names and addresses of the major industrial plants within the SIC area are listed in Table 3 and locations are denoted in Figure 1.

Table 3: Major industries within the Strathcona Industrial Corridor (Environment Canada, 1999a).

Company Name	Company Street Address
Alcan	Sherwood Park
Alberta Envirofuels Inc.	9511 - 17 Street, Edmonton
AltaSteel Ltd.	9401 - 34 Street, Edmonton
AT Plastics Inc.	4405 - 101 Avenue, Edmonton
Celanese Canada Inc.	1250 – Hayter Road, Edmonton
Daam Galvanizing Inc.	9390 - 48 Street, Edmonton
Diversey Lever Canada	2020 -84 Avenue, Edmonton
Edmonton Power - Cloverbar	1515 - 130 Avenue, Edmonton
Imperial Oil	Highway 16A & 34 Street, Edmonton
Interprovincial Pipe Line	Baseline Road, Sherwood Park
Ostrem Chemical Co. Ltd.	2310 - 80 Avenue, Edmonton
Owens Corning Canada Inc.	831 - Hayter Road, Edmonton
Petro-Canada	211 - 106A Avenue, Edmonton
Praxair Products Inc.	9501 - 34 Street, Edmonton
Shaw Pipe Protection	10275 - 21 Street, Edmonton

Figure 1: Map of Capital Health Region showing the proximity of St. Albert and Sherwood Park to Industry.



5.0 RESEARCH APPROVAL BY HEALTH RESEARCH ETHICS BOARD:

The Health Research Ethics Board (HREB) is a joint committee of the University of Alberta Health Science Faculties, Capital Health Authority and the Caritas Health Group in Edmonton, Alberta (HREB, 1998). The purpose of an ethics review is to ensure that the rights of study participants are protected. The multidisciplinary composition of a HREB committee allows its appraisal to have a broad basis. The HREB is responsible for administration of this collaborative ethics review process designed to expedite an ethics review. The HREB is composed of two different boards: HREB-A which focuses on biomedical (invasive) research and HREB-B which focuses on health (noninvasive) research. This study fell under the jurisdiction of HREB-B (HREB, 1998).

Research projects that require review include any health research involving human subjects that is being conducted by persons affiliated with the Capital Health Authority. It is the principal investigator's responsibility to ensure that appropriate ethical review has been received and that approval has been granted prior to the start of data collection. (HREB, 1998).

There was a request for an ethics review that was followed by a series of events. The *HREB Request for Ethics Review* form (HREB, 1997) and the associated *HREB Ethics Review Guidelines for Researchers* (HREB, 1998) were documents required to request an ethics review.

- August 20, 1998 - *HREB Request for Ethics Review* form (Appendix 1) was completed and submitted to HREB-B;
- August 26, 1998 - HREB letter confirming receipt of *Request for Ethics Review* and providing a September 4th meeting date;
- September 4, 1998 - HREB ethics review meeting during which the investigators made a brief presentation on the proposed research and responded to questions from the HREB-B;
- September 8, 1998 - HREB letter requesting revisions to the proposed research to ensure compliance with HREB guidelines;

- September 11, 1998 - University of Alberta letter with the revisions requested by the HREB; and
- September 22, 1998 - HREB letter of ethical approval (Appendix 2) allowing the research to proceed with the blessing of the HREB.

HREB approval had not been received until after data collection began but the HREB was made fully aware of the research schedule on June 29, 1998 and did not express any concerns regarding timeliness of these events.

On September 23, 1998, Capital Health Authority's Regional Research Administration requested that the investigators also receive their approval prior to initiating any research project. The University of Alberta submitted a request for administrative approval on October 2, 1998 and subsequently received a 'Notice of Administrative Approval for Proposed Research' on October 14, 1998 (Appendix 3).

6.0 MATERIALS AND METHODS

> "Extrapolation and practical application of research involves simplification, generalisation, and application of assumptions which may be difficult to test. This is often criticised by researchers as the tight quality standards are mixed with less stringent methods of inference. However, these applications are the main justification of the studies. As a matter of principle, the research on environmental health is oriented towards finding the factors affecting the health of populations and preventing adverse impacts on health. ... The approximate result based on impact assessment from the best available knowledge is always more systematic and clearer than a subjective judgement based on emotions or arbitrary assumptions." (Krzyzanowski, 1997)

6.1 Spatial Sampling Design

6.1.1 Selection of Target Communities

The reason for selecting the communities of Sherwood Park and St. Albert was to test the hypothesis. Alberta Health (1996) reported a public perception that a community's close proximity to industry can result in greater exposure to air pollution and subsequently a higher incidence of illness. Sherwood Park was selected due to it's very close proximity to the SIC and conversely St. Albert was selected due to its not being close to the SIC.

In order to test the hypothesis, it was important to address factors that could bias results of this study. It was impossible to eliminate all such factors in a study of this nature but their influence was minimized through use of a randomized sampling design and selection of similar communities. There were numerous similarities observed between the two communities. In 1998, the total populations were similar, Sherwood Park with a projected population of 44,923 persons (Strathcona County, 1998b) and St. Albert with a population of 49,243 persons (City of St. Albert, 1998).

The age distributions of the two communities were very similar (Figure 2). In both communities, approximately 30% of the residents were 0 to 19 years old, 10% were 20 to 29, 45% were 30 to 54, and 15% were over 55 years. Both communities were populated by predominantly young to middle aged families with children.

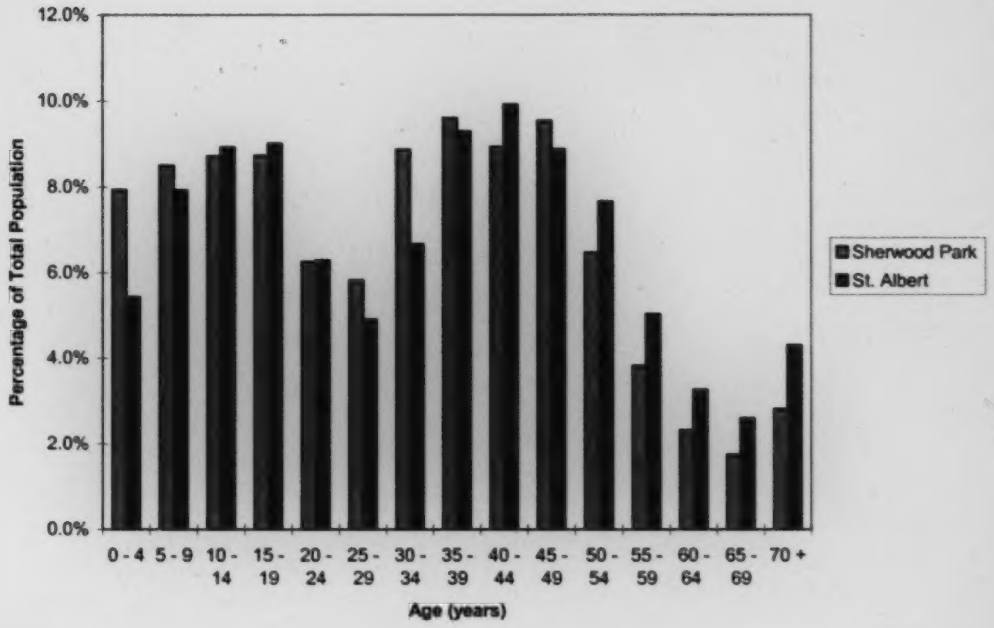


Figure 2: Age distribution for Sherwood Park and St. Albert (Strathcona County, 1995 and City of St. Albert, 1998).

The two communities were also comprised of similar types of dwellings (Figure 3). The communities contained predominantly single family dwellings with greater than 90% of the dwellings categorized as either single family dwellings, duplexes, triplexes, fourplexes or townhouses. In both cases, less than 10% of the dwellings were categorized as either apartments or mobile homes.

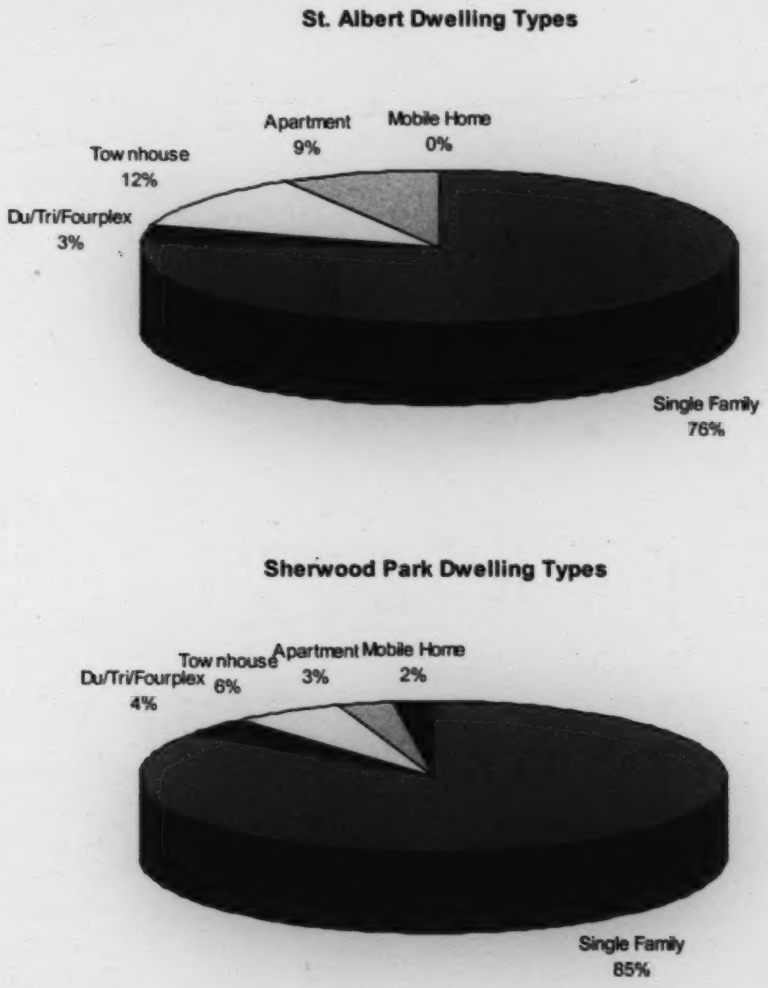


Figure 3: Dwelling types in Sherwood Park and St. Albert. This data excluded persons living in institutions comprising less than 1% of both populations (Strathcona County, 1998 and St. Albert, 1998).

The employment rate and family income levels indicate that the two communities were of a similar socioeconomic status. There were greater than 50% of residents employed with greater than 40% employed full-time in both communities (Figure 4). There was also a similar income distribution in the communities (Figure 5) with about 40% of households making over $70,000 per year and about 70% of the households making over $50,000 per year.

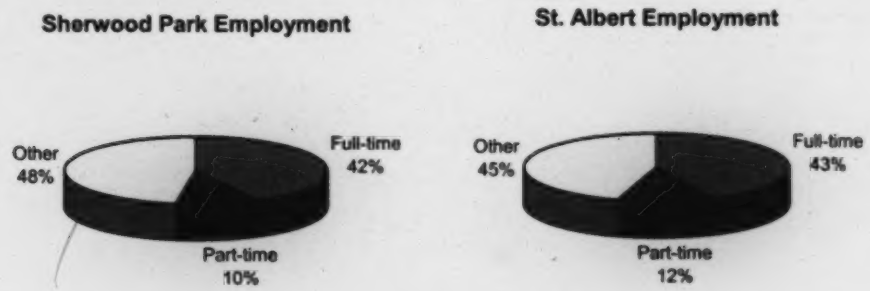


Figure 4: Employment rate for Sherwood Park and St. Albert (Strathcona County, 1998 and City of St. Albert, 1998)

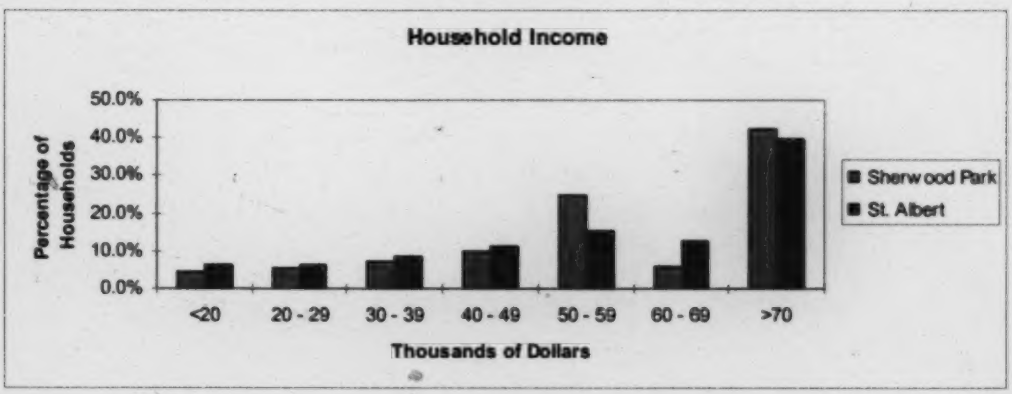


Figure 5: Household income for Sherwood Park and St. Albert (Strathcona County, 1995 and City of St. Albert, 1996)

Hence, the two communities were very similar in that they are both small, urban satellite communities with similar demographic characteristics. They were comprised of similar dwelling types and similar residents by both age and socioeconomic status. Further, they both bordered on a large urban center where they were exposed to similar meteorological conditions.

6.1.2 Selection of Dwelling Units

A form of probabilistic sampling referred to as a stratified sampling approach was used to select dwelling units for sampling. This approach was also used in the TEAM studies (Wallace, 1986a, 1986b, 1988). Probabilistic sampling uses the principle of randomization to ensure that the probability of any randomly selected unit may be determined (EPA, 1983). Stratified sampling divides a population into fairly homogeneous groups called strata, and each sampling unit is selected within each of the strata independent of other strata (EPA, 1983). The strata used within the communities were geographical areas with different proximity to the SIC.

A stratified sampling approach was selected for several reasons. It ensured a good geographical distribution of the samples. If a difference related to proximity were observed, it would allow different strata to be characterized and compared by their proximity to the industrial corridor. It improved upon the feasibility and efficiency of the field sampling operations. Lastly, it further randomized selection of the individual dwelling units (Jhangri, 1998).

A three stage stratified sampling design was developed using the most recent (1998) municipal census data for the target populations, and some current municipal maps for Sherwood Park (1998) and St. Albert (1996) delineating all of the different municipal communities. This final design was reviewed and approved by Gian Jhangri (1998), a statistician with the Department of Public Health Sciences, University of Alberta. The three stages of sampling may be described as:

First Stage Sampling:	proximity strata in relation to SIC established for each community
Second Stage Sampling:	geographical area strata established within each proximity strata
Third Stage Sampling:	random sample taken within each geographical area

The population base that was sampled from was all of the dwelling units within each of the targeted communities. The owner or tenant of randomly selected dwelling units had to consent to be a participant during the recruitment phase of the study. Further, the participant had to meet the following criteria to minimize liability, to maximize operational feasibility, and/or to satisfy the *Health Research Ethics Board* (HREB, 1998):

- is the owner or tenant of the house,
- is at least 18 years of age,
- is physically and mentally capable of participation,
- does not have language barriers, and
- is available for both Fall and Winter phases of sampling.

For purposes of this study, a dwelling unit was defined as a structure that is occupied and can be described as either a single family dwelling, duplex, triplex, fourplex or townhouse. This excluded structures that would be described as an apartment building, collective dwelling or mobile home.

Exclusion of the aforementioned structures from the definition of a dwelling unit was intended to prevent the introduction of additional confounders and to improve operational feasibility. The additional confounders associated with these structures include the diffusion of VOCs between suites and the possibility of parkades in close proximity to sampling sites. Mobile homes were only present in Sherwood Park where they were geographically isolated from the rest of the municipality. It was also reported in the Canadian indoor air quality survey that mobile homes had the lowest concentration for most VOCs (Otson and Meek, 1995). Further, the excluded structures comprise only a small percentage of the total number of dwellings in both communities with ~6% in Sherwood Park (Strathcona County, 1998) and ~9% in St. Albert (City of St. Albert,

1998). This exclusion should not compromise the research objectives as both communities were treated similarly.

The number of dwelling units to be sampled within Sherwood Park and St. Albert was limited by cost. It was deemed prudent to ensure a minimum size of 30 dwelling units be selected from each municipality allowing the central limit theorem to be applied (Khazanie, 1979). This theorem states that if random samples were drawn from any population then for a large sample size, greater than or equal to 30, the distribution will be approximately normal. This would allow parametric tests to be applied during data analysis with such tests being more powerful than the corresponding non-parametric tests (Jhangri, 1998).

The first stage of sampling involved establishing proximity strata in the two target communities. Proximity strata were established in a fashion that ensured the boundaries enclosed entire communities and each of the strata were different distances from the SIC. This required the most recent and accurate census data to be used, which was the 1998 municipal census data. The second condition required an equal number of samples to be taken from each of the strata to allow for good comparison (Jhangri, 1998). Thus, there were four proximity strata established within Sherwood Park with eight samples each, and three strata in St. Albert with ten samples each.

The second stage of sampling involved further division of these proximity strata into smaller geographical strata. Establishment of these strata was to ensure the boundaries enclosed entire communities, to provide good geographical distribution, and to improve operational feasibility. The number of dwelling units selected within each strata was made proportional to the total number of dwelling units within each geographical strata relative to its proximity strata. The resultant strata are shown in the maps in Appendices 4 and 5, and the sampling distributions within both communities are described in Appendix 6.

The third stage of sampling involved taking a random sample of all of the dwelling units within each of the geographical strata. This required an independent and random selection of one dwelling unit from each of the geographical strata in the two target populations. First, the municipal census data was received in electronic format

from the City of St. Albert and the County of Strathcona. The dwelling units were selected using *Microsoft Excel® Version 7.0*: dwellings were sorted by municipal enumeration areas into the geographical strata and then the sampling tool was used to randomly select one dwelling unit for each of the geographical strata. The results of this selection were the random starting dwellings whose specific locations are confidential under the requirements of the HREB (1998).

6.1.3 Participant Recruitment

The sampling of dwelling units requires recruitment of the owner or tenant of the dwelling unit as a participant in the study. Recruitment of the participants involved distribution of a promotional recruitment pamphlet and a door to door campaign. The door to door campaign included the distribution of an Introductory Letter, Information Sheet and Questionnaire: Household Characteristics, completion of a Participant Consent Form and scheduling of data collection visits.

The recruitment pamphlet (Appendix 7) was developed as a method of introducing the study and investigators to potential participants prior to the door to door campaign. The investigators, Capital Health's review team, the HREB, and the public in a test run reviewed the pamphlet prior to final printing. HREB (1998) recommended a reading level of grade 8 be used in documents for the general public. This pamphlet was rated at a Flesch-Kincaid reading level of grade 8.5 by the grammar check in *Microsoft Word® Version 7.0*.

The number of pamphlets distributed was determined by doubling the number of participants needed in each strata. This estimate was based upon previous studies of a similar sampling design that had received a response rate to recruitment of approximately 50% (Wallace, 1986a and 1986b; Otson et al., 1992b). The pamphlets were hand delivered prior to the study on September 1 and 2, 1998 following the Field Recruitment Protocol (Appendix 8).

The primary purpose of the door to door campaign (EPA, 1983) was to recruit participants. The campaign (Visit 1) occurred from September 8 to 19, 1998 during the evenings on weekdays and on Saturday afternoons. The campaign followed the Field

Recruitment Protocol and the Recruitment Campaign Field Procedure described in Appendix 9.

The Introductory Letter (Appendix 10) was intended to further promote the research and was required by HREB (1998). It introduced the Capital Health Authority and University of Alberta as major organizations supporting the research. It also introduced the Capital Health Authority's medical officer of health and the principal investigator. This letter was rated at a Flesch-Kincaid reading level of grade 8.4 by the grammar check in *Microsoft Word® Version 7.0.*

The Information Sheet (Appendix 11) was intended to provide a participant with some information on the study and to provide telephone contacts. This document was required by HREB (1998). It was rated at a Flesch-Kincaid reading level of grade 8.7 by the grammar check in *Microsoft Word® Version 7.0.*

6.1.4 Participant Consent

The participant's consent was documented on a Participant Consent Form (Appendix 12). Two main purposes of this form were to receive the participant's signature confirming their agreement to participate, and to associate the research identification number with the participant's name, address, and phone number. It also served to confirm that the participant understood the study, received the information sheet, understood the risks and benefits, consented to additional analysis outside the scope of this study, and understood that they did not have to participate and were free to withdraw at any time.

The Participant Consent Form was also required by the HREB (1998), who strongly recommended the use of their Consent Template with any necessary modifications to accommodate the study. The Consent Template has a grade 7 reading level (HREB, 1998). It was used for this study with only slight modifications including the addition, at the request of the HREB, of a question asking the participant if they consent to additional analysis of the data at a later date.

6.2 Temporal Sampling Design

6.2.1 Temporal Variation of VOCs

There are seasonal variations in both indoor and outdoor VOC concentrations. In a national Canadian study (Fellin and Otson, 1993), less than 13 % of the variation in indoor VOC concentrations could be attributed to environmental factors such as outdoor temperature, differential temperature, and relative humidity. Typically, the lowest indoor VOC concentrations occur during warmer summer months. The Canadian prairie provinces were observed to have the highest indoor VOC levels during its cooler fall season (Fellin and Otson, 1993). Further analysis of the Canadian data resulted in an observation that indoor temperatures greater than 25°C and outdoor temperatures greater than 15°C were associated with the lowest indoor VOC levels (Otson and Meek, 1995). These results suggest that increased natural ventilation in summer months may result in reduced indoor VOC concentrations.

The Canadian study was supported by a German study that monitored twelve dwellings for 26 two-week periods over a year (Seifert et al., 1989). In the cold season, it was observed that ten houses had total VOC (TVOC) concentrations that were two to three times higher than in the warm season. The other two homes exhibited a fairly constant level of TVOCs throughout the year but they were also observed to have relatively high ventilation rates. A similar seasonal trend was observed when frequency distributions as a function of sampling month were developed from the results of the larger German study of 488 homes (Seifert et al., 1989).

Outdoor VOC concentrations have also been observed to vary on a seasonal basis. Environment Canada has been monitoring outdoor VOC concentrations in Canada since 1987. A substantial annual variation in TVOC concentrations has been observed with the highest concentrations occurring between the months of August and February (Dann and Wang, 1992). It was also observed that benzene concentrations in western Canadian cities were highest in the months of January and February and lowest in the months of June and July (Dann and Wang, 1995).

In view of indoor and outdoor seasonal variations, the fall and winter sampling phases were selected for several reasons. They are both cold seasons in Alberta with the

anticipated higher indoor VOC concentrations associated with less natural ventilation. In Alberta, the highest indoor VOC concentrations have been observed in the fall season (Fellin and Otson, 1993), and some of the highest outdoor TVOC and benzene concentrations have been observed in the winter season (Dann and Wang, 1992). Thus, the fall season should represent a worst case scenario for indoor VOC levels, and the winter season should represent the worst case scenario for outdoor VOC levels in Alberta.

There are also daily variations in indoor and outdoor VOC concentrations. Since 1987, Environment Canada's monitoring of outdoor TVOC levels illustrate a substantial daily variation with the highest levels occurring Monday through Friday and the lowest concentrations occurring on Saturday and Sunday (Dann and Wang, 1992). It is likely that this pattern is a result of greater overall use of the automobile during workweeks (Monday through Friday) than on weekends. A similar trend was observed with outdoor benzene concentrations where most Canadian sites reached their maximum midweek, and had lower median, 75^{th} and 95^{th} percentile concentrations on weekends. The urban sites, influenced more by urban industry, exhibited a smaller difference between weekday and weekend benzene concentrations (Dann and Wang, 1995).

There may also be hourly variations in indoor VOC concentrations. In two national studies, it was observed that indoor VOC concentrations were highest during the times of day when human activity levels within a dwelling are highest (Wallace, 1986; Seifert et al., 1989). Evidence of a "personal activity cloud", supported by the ratio of PEM to MEM ranging from 1.2 to 3.3 in residential dwellings, further supports the argument that it is human activity which is associated with increased indoor VOC levels (Rodes et al., 1991). The Canadian human activity pattern survey (CHAPS) observed that Canadians spend less time at work or school on the weekends and more time either at indoor locations other than home or outside (Leech et al., 1996). Thus, both the hourly and daily variations in indoor VOC concentrations are most likely due to respective variations in the level of human activity within a particular dwelling.

Temporal variations in VOC concentrations were accounted for in the study design. Any hourly variations were not important to the study objectives. In addition, the method of monitoring the VOCs uses a 24-hour time weighted average that does not

capture fluctuations during the day. The daily variations were accounted for by using representative sampling periods as described in next section.

6.2.2 Participant Scheduling in Fall

Data collection visits were scheduled during the recruitment campaign (visit 1). Visits were scheduled between September 21 and October 30, 1998. There were two visits scheduled with participants at the same time on consecutive days (sampling block) to accommodate drop-off (visit 2) and pick-up (visit 3) of the air samplers. The participants were given a reminder card with dates and time of these visits, and participants scheduled in October were also given a reminder telephone call the day before the second visit.

A monthly scheduling template (Appendix 13) was developed as an aid for scheduling participants. There were weekday sampling times available on Monday/Tuesday, Tuesday/Wednesday, Wednesday/Thursday or Thursday/Friday, and weekend sampling times available on Friday/Saturday and Saturday/Sunday. There were a total of 16 sampling blocks available of which 75% of these were weekday sampling blocks and 25% of these were weekend blocks. The division of sampling blocks closely represented a 7-day week where 71% of the week is weekdays and 29% of the week is weekend.

A daily scheduling template (Appendix 15a) collected all of the necessary information for field investigators to make their appointments. This included the date, time, participant's name, street address, municipality, and telephone number. The booking times were kept as flexible as possible to accommodate participants' schedules. The daytime bookings were between the hours of 10:30 a.m. and 4:30 p.m. Evening bookings were from 6:00 p.m. to 7:15 p.m. in one municipality, and from 7:45 p.m. to 9:45 p.m. in the other community. There was 15 minutes left between participant visits in the same municipality, and 30 minutes left between participant visits in different municipalities to allow for travel time.

6.2.3 Participant Scheduling in Winter

Winter scheduling procedures were very similar to the fall, with the basic differences described below. There was a telephone campaign conducted in early January 1999 that involved calling all of the fall participants and scheduling data collection visits between January and February 1999. There were two visits scheduled with participants at the same time on consecutive days.

Another monthly scheduling template (Appendix 14) was developed as an aid for scheduling participants. There was weekday sampling available on Monday/Tuesday, Tuesday/Wednesday, Wednesday/Thursday, and Thursday/Friday and weekend sampling available on Friday/Saturday. There were a total of 17 sampling blocks available of which 71% were weekday sampling blocks and 29% were weekend blocks, which again were representative of a 7 day week.

The daily scheduling template (Appendix 15b) was essentially the same as the one used in fall. The investigators decided to remove the last sampling window (9:00 to 9:45 p.m.) from the fall template as it was not a popular choice with participants. Thus the winter scheduling template had daytime bookings from 10:30 a.m. to 4:30 p.m. and evening bookings from 6:00 p.m. to 9:00 p.m.

6.3 Air Sampling and Monitoring

6.3.1 Selection of Air Sampling Methodology

The measurement of an airborne substance may be categorized into the three basic processes of sampling, separation and detection (NAS, 1991). This study focused on residential air quality through the collection of micro-environmental air samples, laboratory analysis (separation and detection) of these samples, and completion of a microenvironmental questionnaire. In selecting a methodology, one must consider three major criteria --- the research objectives, operational requirements and technical requirements.

Research objectives required a methodology that enabled the measurement of a multitude of VOCs at environmental concentrations (ppbv to pptv) at multiple locations within two municipalities in a manner that was representative of human exposure.

Operational requirements had to consider budget limitations and needs of a community based study. Firstly, the sampling design and budget limitations required numerous air monitors at a low cost per unit. Secondly, the sampling design required air monitors to be transported and placed unsupervised, indoors and outdoors, at multiple locations requiring them to be rugged, portable, compact and quiet. Lastly, this was a community based study requiring voluntary participants which means that it must be designed in a manner that ensures a good response rate and retains participants for the duration of the study. Thus, the participant's burden had to be minimized by ensuring that the air monitor was not aesthetically displeasing (eg. odorless, unobtrusive, and quiet), and that the air monitor could be quickly set-up and retrieved.

Lastly, the investigators had to consider technical requirements of the study in selecting a methodology. The National Academy of Sciences (1991) suggested consideration of the following criteria:

1. Sensitivity - "A method with adequate sensitivity is one in which an analyte can be detected at or below the level at which an adverse human-health problem is anticipated or observed."
2. Selectivity - "A method that is selective (or specific) is one in which the response observed for a desired analyte is due only to that analyte and is not from an interfering analyte or artifact produced during sampling or analysis."
3. Rapidity - "A method is considered rapid if either the sampling or analysis can be carried out on a time frame that is short compared with any adverse health response observed in an exposed individual."
4. Comprehensiveness - "A comprehensive method often is desired for analyzing all analytes that might be responsible for an adverse health effect, particularly when a synergistic effect between analytes might exist."
5. Portability - The sampling device is small, light, quiet, rugged, low power consumption, battery operated, and has a high environmental tolerance.
6. Cost - "The cost of sampling and analyzing an analyte in a statistically sound manner should not be prohibitive."

The two basic approaches for air quality measurement are field sampling and analysis using portable instruments, or field sampling with laboratory analysis. In a

review of the different measurement techniques (NAS, 1991), the sensitivity, selectivity and comprehensiveness of an instrument appear to be compromised to improve upon it's portability, rapidity and affordability. The research objectives required a multitude of individual VOCs to be measured at environmental concentrations which does not allow sensitivity, selectivity and comprehensiveness to be compromised. Portable instruments do not meet technical requirements of the research objectives, and they cannot possibly meet the operational requirements described above. Hence, it was evident that the best available option was field sampling with laboratory analysis.

Calgary Health Services (1993) described the three basic methods of air sampling as instantaneous (grab) measurements, time weighted average measurements, or continuous measurements. A grab measurement is from a grab sample taken over a short time period (eg. several minutes) and it is used to determine the existence of suspect agents or to determine an episodic concentration. A time weighted average (TWA) measurement is from a sample taken over a longer period of time (eg. several hours to numerous days) which yields the mean concentration of a substance over that period of time. Lastly, a continuous measurement is a series of instantaneous measurements taken and recorded over a longer time period, it allows for both the peak concentrations and time weighted average concentrations over that time period to be determined.

A sampling method yielding a TWA measurement was considered the best option for meeting the research objectives and the technical requirements. Instantaneous and continuous measurement methods both involve taking grab samples of VOCs at environmental concentrations. The small mass of an individual VOC in a grab sample reduces the overall sensitivity of the measurement methodology, possibly to below an analytical method's detection limit. Sensitivity may be increased by increasing the volume of the air sampled by sampling over a longer period but results in a TWA measurement. The TWA measurement does not allow for detection of peak concentrations which makes use of these data questionable for the health risk assessment of acute health effects (NAS, 1991).

Two basic air sampling methods are active and passive sampling (NAS, 1991). An active sampler uses a pump to pull the air sample through a collection device. A passive

sampler is based upon principles of diffusion delivering air contaminants to a collection medium. An air sample containing VOCs may be collected as a whole air sample in either an electropolished steel canister, in Tedlar® bags or in Teflon® bags (Keith, 1991). It may also be collected as a concentrated sample in a cryogenic trap, on an absorbent, or on a series of absorbents (multisorbent). There are many different absorbents and sampling devices available which may be used in various combinations to concentrate the air sample (NAS, 1991). In the United States, the two preferred methods of sampling for VOCs are active sampling using Tenax® as an absorbent, and grab sampling using Summa® canisters (Wallace, 1993). In Europe, the two most commonly used absorbents are activated carbon and Tenax® (Wallace, 1993).

The passive sampler was considered to be the best available air sampling methodology for a community based study of VOCs. A passive sampler in relation to an active sampler has a less accurate sampling rate and has a greater chance of chemical transformations on the absorbent with the longer sampling time that is usually needed (NAS, 1991). However, a passive sampler does not require elaborate equipment, is less costly, is easier to implement, and results in better cooperation by participants (NAS, 1991). Thus, this method was believed to meet operational requirements and allow the research objectives to be achieved.

6.3.2 Theory of Passive Air Samplers

A passive sampling device (PSD) is an air sampler that uses the principle of diffusion across an air gap to drive mass transfer of gaseous substances onto a collection medium. Scientists made one of the first scientific attempts to create a quantitative diffusive sampler in 1973, when a passive tube sampler for sulfur dioxide was designed (Brown, 1993). Current PSDs usually consist of a diffusion barrier, a diffusion zone, and a collection medium.

The diffusion barrier controls the air sampling rate by permeation and/or diffusion control processes (Palmes, 1980). A permeation-limited PSD uses a membrane in which VOCs are soluble and a diffusion-limited PSD uses a porous membrane. The diffusion barrier creates the geometric region of quiescent space, the diffusion zone or air gap, through which mass transport is achieved by diffusion. The collection medium used for VOCs is usually either activated carbon or a synthetic sorbent such as Tenax®.

Properties of the diffusion barrier and geometry of the diffusion zone determine the rate of sampling (Alberta Research Council, 1995). For mass transport to be independent of wind speed and proportional to ambient concentration, the rate of mass transport through the diffusion barrier should be equal to that through the diffusion zone. This would require resistance to mass transport of both the diffusion barrier (r_1) and the diffusion zone (r_2) to be equal. The badge-type PSD with a short diffusion zone will have a negligible r_2 whereas the tube-type PSD with a long diffusion zone will have $r_2 > r_1$. However, since each individual VOC has a different diffusion coefficient, no multiple compound PSD can have an ideal configuration for all gases (Alberta Research Council, 1995).

In selecting a PSD, the critical limits for consideration with high exposure concentrations are capacity and uptake rate of the sorbent, and with low exposure concentrations are response time and sensitivity of the PSD (Harper and Purnell, 1987). Generally, VOCs occur at very low concentrations in indoor and outdoor air (Keith, 1991). Hence, the badge-type PSD appears to be the best available sampler for this study because it meets the critical limits of fast response times that are in the order of seconds (Harper and Purnell, 1987), and it can achieve sufficient sensitivity (Brown, 1993).

The mass of a compound sampled by a PSD is determined by the compound's environmental concentration, its rate of sampling and length of the sampling period. The environmental concentration may fluctuate throughout the sampling period. The selected sampling period should ensure a representative sample, provide sufficient sensitivity and avoid over-saturation of the sorbent. As described by Fick's 'first law of diffusion': the rate of sampling is directly proportional to the coefficients of diffusion of the gas being sampled, the cross-sectional area of the diffusional path, and the concentration of the gas; it is inversely proportional to the length of the diffusion path (Palmes, 1980).

Determination of the environmental concentration of an analyte using a PSD is based upon Fick's 'first law of diffusion' (Harper and Purnell, 1987):

$$J = -D \times \left[\frac{dc}{dx}\right] \qquad \textbf{Equation 2}$$

where,

J = diffusion flux, moles/cm^2/s
D = coefficient of diffusion, cm^2/s
dc ~ (environmental concentration - interface concentration), moles/cm^3
dx ~ (length of the diffusion path), cm

The mass sampling rate (m) may also be determined from the 'first law of diffusion' (ACGIH, 1988):

$$M = J \times A = \left[\frac{D \times A}{L}\right] \times (Cs - Cb) \qquad \textbf{Equation 3}$$

where,

M = mass flow rate, moles/s
J = diffusion flux, moles/cm^2/s
A = cross-sectional area of diffusion pores, cm^2
D = coefficient of diffusion, cm^2/s
L = diffusion path length, cm
Cs = environmental concentration of analyte, moles/cm^3
Cb = blank concentration of analyte, moles/cm^3

The volumetric sampling rate may also be determined from the 'first law of diffusion' and is represented by (Shields and Weschler, 1987):

$$\frac{m}{t \times Ca} = D \times \frac{A}{L}$$ **Equation 4**

where,

m/(t Ca) = volumetric sampling rate, cm^3/s
m = mass of analyte sampled, ug
t = sampling period, s
Ca = ambient (environmental) concentration of analyte, ug/cm^3
D = diffusion coefficient, cm^2/s
A = cross sectional area of diffusion surface, cm^2
L = diffusion path length, cm

Lastly, the environmental concentration of the analyte may be determined by transposing Equation 3 into:

$$Ca = \frac{m \times L}{D \times A \times t}$$ **Equation 5**

where

- D is a constant determined by the analyte and membrane characteristics
- L / A is a constant determined by the sampler's geometry
- m is the measured mass of analyte
- t is the measured time of sampling

The diffusion coefficients (D) for a particular PSD may be either experimentally determined or it may be calculated from the empirical relationship described by the Hirschfelder equation (3M, 1992). Diffusion coefficients can often be found in the literature (Harper and Purnell, 1987).

It was important to know the limitations of a method so they could be accounted for in the study design and in interpretation of the results. In determination of the environmental concentration of an analyte, it was assumed that mass of analyte measured during analysis was representative of the concentration gradient (dc) across the diffusion zone which was in turn representative of the environmental concentration during sampling. However, concerns documented in the literature on these assumptions and use of PSDs are their insensitivity to both low concentrations and fluctuations in concentration, and sampling biases resulting from both environmental conditions (temperature, wind speed and relative humidity) and from the sampler's efficiency (Harper and Purnell, 1987; Brown, 1993; Gagner, 1996; and Tang, 1997). These

limitations are dependent on the design of the specific PSD and are discussed in the following section in relation to the PSD selected for use in this study.

6.3.3 The 3M OVM-3500

6.3.3.1 Description

The badge-type PSD used in this study was the 3M® Organic Vapor Monitor (OVM) 3500 (St. Paul, MI). The body of the monitor consisted of a circular plastic casing that was about 1 cm in depth and about 4 cm in diameter. The plastic casing houses the diffusion barrier and the collection medium, and has a metal 'alligator' clip attached to it for affixing the monitor. The diffusion barrier is a Teflon® membrane cover mounted in the face of the monitor. The diffusion zone is an air gap between the Teflon® membrane and the inside-back of the monitor. The collection medium is an activated carbon pad held in place on the inside-back of the monitor by a plastic frame. A schematic of the OVM-3500 is shown in Figure 6.

Figure 6: Schematic of 3M OVM-3500.

6.3.3.2 Limitations of the 3M OVM-3500

Many of the commercial PSDs, including the 3M OVM-3500, were originally designed for monitoring concentrations approaching occupational threshold values (as cited in Otson et al., 1992a and Gagner, 1996). Recognition of the excellent operational feasibility of PSDs as micro-environmental monitors generated a lot of interest but with ongoing concerns. However, the concerns expressed have primarily been based upon

theoretical interpretations or results of laboratory experimentation. There have been few efforts to evaluate the use of PSDs for monitoring VOCs under typical environmental conditions (Otson et al., 1992a).

Temperature (T) is an environmental condition that is a potential source of sampling bias. The Hirschfelder equation and Tang et al. (1997) using the ideal gas law both demonstrated that D is a function of ($T^{3/2}$), and 3M (1998a) has acknowledged this by providing a temperature correction factor. Cold temperatures increase the adsorption efficiency of carbon (Gagner, 1996) which could increase the concentration gradient driving the sampling rate. In a review of PSDs, Harper and Purnell (1987) stated that the effect of temperatures from 0°C to 40°C have a negligible effect. Gagner (1996) concluded in a validation of the OVM-3500 that temperatures from minus 15°C to plus 40°C did not have a significant effect over 24-hour sampling periods.

Relative humidity (RH) is another environmental condition that is a potential source of sampling bias. A PSD concentrates a multitude of VOCs on the activated carbon absorbent. Various compounds compete for adsorption sites with those with the highest affinity being preferentially absorbed. The most interfering substance to this process of adsorption is water vapor (Harper and Purnell, 1987). A steep rise in the Brunauer adsorption isotherm has been observed to occur at a relative humidity of 50% to 80%, and reduced adsorption of VOCs has been experimentally demonstrated (Harper and Purnell, 1987). Further, 3M acknowledges a reduced capacity of the OVM-3500 at a relative humidity of greater than 50% (3M, 1998a).

Wind speed is the last environmental condition to consider as a potential source of sampling bias. Wind speed or indoor air velocity in the immediate vicinity of the PSD is referred to as the face velocity. A minimum velocity parallel to the face of the sampler is needed in order to prevent starvation of the layer of air (boundary layer) immediately adjacent to the diffusion barrier (Harper and Purnell, 1987). For the concentration gradient that drives sampling to be maintained, the boundary layer should theoretically be reduced to zero (Brown, 1993; Tang et al., 1997). Minimum face velocities found in the literature for badge-type PSDs range from 5 to 10 cm/s (Harper and Purnell, 1987) to 130 cm/s (Tang et al., 1997).

There is sufficient evidence to demonstrate that face velocity affects the sampling rate, but it is unknown whether the effect is significant enough to be detected at environmental concentrations of VOCs. 3M (1998a) advises that the OVM-3500 can be used for either personal or area monitoring but in area monitoring it should not be used in areas with limited air movement. In independent studies of the OVM-3500, there was less than a 10% variation observed in sampling rates with face velocities ranging from 1 cm/s (0.036 km/h) to 1200 cm/s (43.2 km/h) (as cited in Gagner, 1996). The typical outdoor wind speeds in Alberta as reported by Environment Canada range from 6 to 22 km/h (Tang et al., 1997). Typical indoor air velocities reported by ASHRAE are 15 cm/s (Gagner, 1996) but another study reported that greater than 70% of indoor air velocities are less than 10 cm/s (Rodes et al., 1991). It is apparent that the typical outdoor wind speed should be sufficient to prevent starvation of the PSD, but what the typical indoor air velocities are and whether they are sufficient to ensure an accurate measure of exposure is unknown.

The insensitivity to low or to fluctuating environmental concentrations is another concern reported in the literature relating to PSDs (Coutant and Scott, 1982; Harper and Purnell, 1987; Gagner, 1996). A sufficient sensitivity to environmental concentrations may be achieved in PSDs by minimizing the amount of artifacts in samplers during manufacturing, by increasing length of the sampling period, and by increasing the sensitivity of sample analysis (Brown, 1993). The need for lower and more consistent blanks in PSDs was reported by Coutant and Scott in 1982, and this has lead to improvements in this area (Coutant and Scott, 1982; Gagner, 1996). PSDs may be made more sensitive to transient concentration peaks by shortening the length of the diffusion path resulting in faster response times (Harper and Purnell, 1987), as found in badge-type PSDs.

Lastly, the efficiency of a PSD is another concern expressed in literature (Shields and Weschler, 1987; Gagner, 1996). A PSD's efficiency is described by the collection medium's ability to both adsorb and retain analytes. The collection medium used in the OVM-3500 is activated carbon which is described as a strong adsorbent (Harper and Purnell, 1987; Brown, 1993). Strong adsorbents have Langmuirian isotherms, where

adsorption is a function of dose and there is a saturation point after which no more gases can be adsorbed (Harper and Purnell, 1987). Gagner (1996) concludes from his literature review that the OVM-3500's efficiency should be reliable to a point of over-saturation. Shields and Weschler (1987) found the amount of material desorbed from an OVM-3500 was significantly less than the saturation capacity reported by 3M, even in their most extreme exposure case involving three weeks of painting and construction. Thus, it is unlikely that a problem of exceeding saturation would be experienced in this study which was sampling residential concentrations over a twenty-four hour period.

It is important to be aware of all of the above limitations so that they may be taken into consideration during design of the study. However, the implication of these limitations on the method of sampling can only truly be appreciated by testing its ability to measure environmental VOC concentrations. This is accomplished through validation studies of the PSD.

6.3.3.3 Validation of the 3M OVM-3500

In the literature review, the favored method of validation was the comparability of the method in question to currently accepted methods. The 3M OVM-3500 is a charcoal badge-type PSD. The charcoal badge is the diffusive equivalent to the charcoal tube used in active sampling (Brown and Monteith, 1995). Thus, many of the validation studies of charcoal PSDs compare the results of these devices to those yielded from active sampling with a charcoal tube. Active sampling with a charcoal tube has been used in the occupational health field for over 20 years with a methodology was standardized by the National Institute of Occupational Health and Safety (NIOSH) (Gagner, 1996) There have been both chamber studies in the laboratory and field studies performed to validate the 3M OVM-3500.

The 3M OVM-3500 has been validated for sampling at both occupational and environmental VOC concentrations. It has a wide range spanning six orders of magnitude from the tenths of $\mu g/m^3$ to g/m^3 (Shields and Weschler, 1987). Otson and Fellin (1992) observed reliable measurements of VOC concentrations ranging from 50 to 5000 $\mu g/m^3$. As discussed earlier, this study tested the lower limits of detection or method detection limits (MDL) in its attempt to measure environmental VOC concentrations over a

relatively short time period. The MDL is "the lowest concentration of an analyte that can be measured by a given procedure..." (EPA, 1994).

MDLs have been determined in other studies that used similar methodologies to the present research including sampling with the 3M OVM-3500, carbon disulfide solvent extraction, and GC/MS analysis. Shields and Weschler (1987) reported a MDL of 0.06 $\mu g/m^3$ for a four week sample, Seifert and Abraham reported a MDL of 0.45 $\mu g/m^3$ for a four week sample, and Otson and Fellin (1992) reported a MDL of 2.0 $\mu g/m^3$ for a 24 hour sample. The MDL is not only dependent upon the method but upon the compound, but these studies report a single MDL for a multitude of compounds. The MDL determination was not stated in these studies, hence it is assumed that these values represent a central measure of a range of MDLs for the different target compounds. Based upon the reported MDLs, it would appear that the OVM-3500 has the ability to sample typical environmental VOC concentrations that range from approximately 1 $\mu g/m^3$ to 10 mg/m^3 (Brooks and Davis, 1992).

Sampling periods over which the OVM-3500 has been validated for ranged from 5 hours to 1500 hours (Shields and Weschler, 1987). It has also been validated for the 24-hour sampling period used in this study (Otson and Fellin, 1992; Gagner, 1996).

The passive and active sampling systems appear to exhibit no significant difference in either accuracy or precision. The precision of the OVM-3500 has been reported as being 13% (Shields and Weschler, 1987), 7 to 10% (Otson and Fellin, 1992), and up to 25% for TWA benzene concentrations of more than 5 $\mu g/m^3$ and for toluene concentrations of more than 10 $\mu g/m^3$ (Gagner, 1996).

The well designed PSD "may be regarded as truly integrating devices with accuracies similar to those of active samplers." (Brown and Monteith, 1995). NIOSH recommends that air monitors be able to obtain an accuracy of ±25% for 95% of the samples tested within the range of 0.5 to 2 times the air quality standard (Brown and Monteith, 1995). For an 8 hour sample, 3M (1998b) states that the OVM-3500 has an accuracy of ±25% at 1.0 ppm and ±35% at 0.5 ppm. Gagner (1996) reports that the OVM-3500 has an accuracy of ±25% for measuring TWA concentrations of benzene

from 5 to 20 $\mu g/m^3$ or for toluene from 5 to 30 $\mu g/m^3$, and that its accuracy is ±50% below these concentration ranges.

In chamber studies, Cohen et al. (1990) reported that others found less than 21% difference between the OVM-3500 and active sampling methods. Seifert et al. (1989) observed less than a 22% difference between the OVM-3500 and predicted VOC concentrations. Cohen et al. (1990) found less than 25% difference between the OVM-3500 and both the predicted and active sampling results. Gagner (1996) observed good correlation between the OVM-3500 and the active sampling method with an accuracy of ±25% at typical environmental concentrations.

In Canada, there have been field studies performed that evaluated the effectiveness of the OVM-3500 for air sampling of indoor and outdoor environmental VOC concentrations. Otson and Fellin (1992) reported the OVM-3500's results were within 15% of results from active sampling using SKC charcoal tubes, and that the two methods had excellent correlation ($R^2 > 0.96$). Gagner (1996) also performed a field co-location of the OVM-3500 with Summa® canisters and reported excellent correlation between results from these two sampling methods.

Hence, validation studies confirm that the OVM-3500 is an acceptable method of sampling indoor and outdoor VOCs under many different environmental conditions.

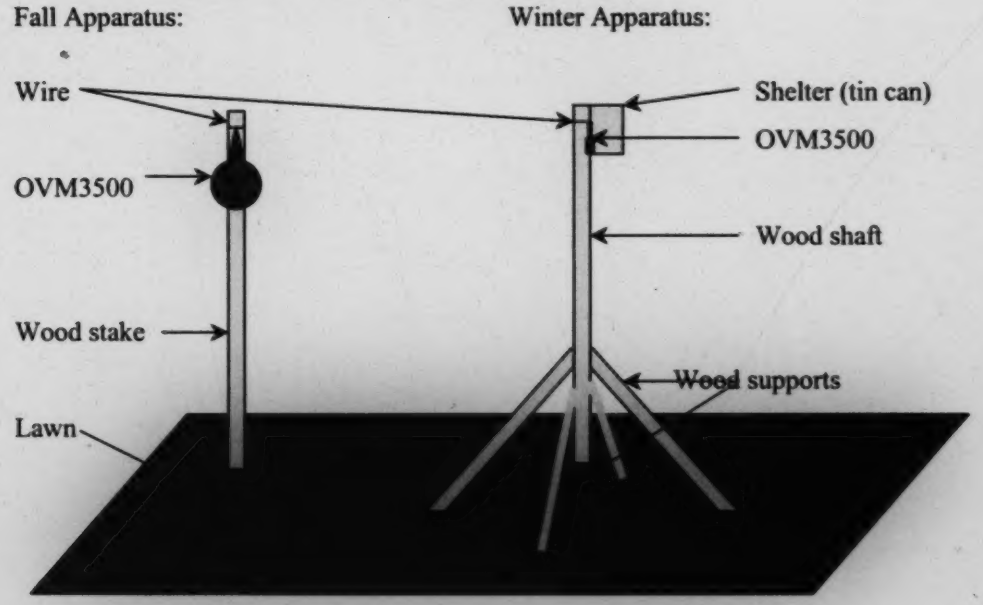
6.3.3.4 Field Procedure

The air sampling procedure used in the field (after 3M, 1998b) involved the deployment of the PSD in a common living area (Visit 2). The common living area was sampled as the area most likely to have the highest level of human activity and exposure. The room to room variability in small residences has been observed to be low in residences with operating central ventilation systems (Otson and Fellin, 1992). It is probable that ventilation systems would be in frequent operation during the coldest seasons of the year. Twenty-four hours after deployment, the PSD was retrieved (Visit 3), data log entries were made, and the PSD was stored in a 4°C refrigerator until the sample was extracted. The equipment requirements (Appendix 16a), indoor sampling procedures

(Appendix 16b) and outdoor sampling procedures (Appendix 16c) are detailed in the Appendices.

The air sampling procedures used for the two periods (fall and winter) were essentially the same. The outdoor mounting apparatus had to be changed in the winter season to accommodate frozen ground and snowfall. The outdoor mounting apparatus used in the fall season was a wooden stake driven into the ground and the one used in winter was a quadrapod with a shelter over the PSD (Figure 7).

Figure 7: Schematic of Outdoor Mounting Apparatuses.



6.3.3.5 Quality Assurance and Quality Control

It is important to have a quality assurance and quality control program in all components of the study. This allows one to maximize the precision and accuracy of the results, minimize bias to the results, and ensure results are representative of the environment being sampled. This was achieved in the air sampling component of the overall methodology through the performance of field blanks, field replicates, adherence to air sampling procedures and through proper storage.

Field blanks were collected to allow for the determination of any background contamination to the PSD. The accuracy of the results was improved by deducting background VOC quantities from the measured VOC quantities. Field blanks were performed every week during the two sampling seasons and were performed alternately between the indoors and outdoors. Procedures for collecting a field blank are described in Appendix 17.

Replicates were performed to allow a determination of the precision of the air sampling methodology. The replicates were performed every week during the two sampling seasons and were performed alternately between the indoors and outdoors. The procedure for performing the replicates is also described in Appendix 16d.

The air sampling procedures outlined in Appendix 16 was adhered to closely. This was to maximize accuracy and precision and to minimize bias of the results. This should also ensure the air sample is representative of the microenvironment being sampled.

For the sample to remain representative, it is also important for the integrity of the sample to be maintained during storage. The efficiency of desorption may be affected by relative humidity during sampling and by the storage method after sampling. It was observed that VOC recovery for most compounds was not significantly affected by 80% humidity during sampling and up to three weeks storage at room temperature (3M, 1996). However, some VOCs showed significant losses due to degradation by adsorbed water under these conditions including acetone, methyl butyl ketone, methyl ethyl ketone, and vinyl acetate. Hence, the manufacturer recommends that the PSD be stored for less than three weeks at room temperature, and to minimize losses of less stable compounds that it be kept refrigerated (3M, 1996). This is reflected in the air sampling procedures, Appendix 16, which require storage of the PSD at 4°C for no more than one week prior to extraction.

6.3.4 Temperature and Relative Humidity Monitoring

The manufacturer and some literature suggested that temperature and relative humidity during sampling could affect sampling rate of the PSD. Previous discussion on validation of the OVM-3500 made it clear that the OVM-3500 would perform well under typical indoor and outdoor environmental conditions. However, it was still considered prudent to monitor the sampling conditions. The only environmental conditions monitored in a national Canadian study were temperature and relative humidity (Otson et al., 1992b). This study measured the same parameters.

The indoor temperature was measured during deployment and retrieval of the PSD. Temperature was measured in the same room the PSD was placed and the result recorded in the Field Data Log. The measurement during deployment was recorded as the 'start temperature' and during retrieval as the 'finish temperature'.

The indoor temperature was monitored with a metric dial-type temperature probe. The temperature probe was a Cooper® CT220C (Middleton, CT, U.S.A.). The temperature probe has a reported accuracy of ±2°C and it was tested against the Q-Trak, another instrument used in this study, and found to be within the manufacturer's reported accuracy. The Q-Trak has a reported temperature accuracy of ±0.6°C (TSI, 1996).

Indoor relative humidity was also was measured during deployment and retrieval of the PSD. Relative humidity was again measured in the same room the PSD was placed and the result recorded in the Field Data Log. The measurement during deployment was recorded as the 'start relative humidity' and during retrieval as the 'finish relative humidity'.

Indoor relative humidity was monitored with an IAQ instrument that uses a thin film capacitive sensor. The instrument was a TSI® Q-Trak IAQ Monitor, Model 8551 (St. Paul, MN, U.S.A.). TSI® reported an accuracy of ±3% for Q-Trak relative humidity measurements (TSI®, 1996). The instrument received a factory calibration in May, 1998, shortly before the study began in September, 1998.

The outdoor meteorological conditions reported in Appendix 23 were reported by the Edmonton city center airport's meteorological station (Environment Canada, 1998 and 1999).

6.4 Laboratory Desorption

6.4.1 Selection of Methodology

After air sampling, either solvent or thermal desorption may be used to recover the VOCs from the PSD's sorbent for analysis (Keith, 1991). For many years, the most common method of sampling VOCs at occupational concentrations was by collecting them on activated carbon followed by solvent (carbon disulfide) desorption (Wallace, 1991). However, at environmental concentrations this method was found to lack sensitivity and led to the development of synthetic sorbents in the mid-1970s. The synthetic sorbents could be heated to high temperatures without degradation allowing thermal desorption to be used for VOC recovery (Wallace, 1991).

Thermal desorption for VOC recovery from a synthetic sorbent has both its benefits and limitations (Otson and Fellin, 1992; Wallace, 1991; Keith, 1991). The major benefit to a synthetic sorbent as compared to activated carbon is its greater sensitivity. The method has greater sensitivity as it does not dilute the collected sample and the entire sample is desorbed (Otson and Fellin, 1992; Keith, 1991). The procedure also uses fewer analytical operations than solvent desorption (Wallace, 1991) with less opportunity for error to be introduced. Further, the synthetic sorbent, Tenax®, is resistant to humidity due to it's hydrophobicity (Wallace, 1991).

There are limitations to thermal desorption of a synthetic sorbent, such as Tenax®. The limitations associated with the thermal desorption include the absence of analytical replicates due to use of the entire sample and decomposition of some VOCs due to pyrolysis. The limitations associated with Tenax® include its inability to retain more volatile VOCs and high background levels of benzene, styrene, and toluene (Otson and Fellin, 1992; Wallace, 1991; Keith, 1991). However, for the purposes of this study, the greatest limitation was that the activated carbon used as a sorbent in the OVM-3500 would degrade with thermal desorption.

Hence, the recommended method is solvent desorption (3M, 1997). The major disadvantage of this method is that the large volume of solvent required for liquid desorption results in reduced analytical sensitivity and higher method detection limits (NAS, 1991). However, its lower sensitivity can be compensated for by sampling larger

volumes of air (Keith, 1991; Wallace, 1991), which also helps to overcome any background contamination that may be present on the PSD (Wallace, 1991). This may be accomplished with a PSD by increasing the sampling time.

The particular solvent used to recover VOCs was dependent upon properties of the targeted compounds. In this study, the solvent recommended by 3M for the targeted VOCs was carbon disulfide (3M, 1998b). Carbon disulfide is usually employed for extraction of organics from carbon adsorbents (Coutant and Scott, 1982), as it is one of the more efficient solvents for this purpose (Shields and Weschler, 1987). It was important that high purity carbon disulfide be used but even high grade carbon disulfide contains variable amounts of organic contaminants in different bottles (Fellin, 1998). Hence, Fellin (1998) recommended that the high purity carbon disulfide be cleaned prior to solvent desorption using a procedure described in Appendix 19a.

6.4.2 Laboratory Desorption Method

The recommended extraction procedure (3M, 1997) is briefly described here and in greater detail in Appendix 18. The extraction procedure involved injecting 1.5 mL of high purity carbon disulfide into the PSD and then gently agitating it for 30 minutes. The liquid extract was then decanted into 2.0 mL vials and stored in a –50°C freezer until the laboratory analysis could be performed.

6.4.3 Quality Assurance and Quality Control

There was quality assurance and quality control in the laboratory desorption methodology. This included use of very clean equipment, use of purified high grade carbon disulfide, accurate and precise measurement of carbon disulfide, close adherence to laboratory desorption procedures, and determination of the desorption efficiencies for the various VOCs.

In order to prevent contamination of the sample, the laboratory equipment used was kept very clean by following procedures outlined in Appendix 18b, and high grade carbon disulfide was used only after further purification as outlined in Appendix 19a. The laboratory purification procedure should improve consistency of the quality of carbon

disulfide (Fellin, 1998). The purity of carbon disulfide and effectiveness of the purification procedure were tested by taking a sample for analysis of both the unpurified and purified high grade carbon disulfide for each batch of PSD desorptions.

Accuracy and precision in the measurement of carbon disulfide was ensured through the use of careful laboratory techniques and calibration of both the Hamilton® syringe and the Sigma® micropipette. The fall extraction used the Hamilton® syringe to dispense the carbon disulfide into the PSD and the winter extraction used the Sigma® micropipette. The calibration procedure is outlined in Appendix 19b.

Accurate determination of the quantity of VOC collected by activated carbon is dependent upon efficiency of the desorption procedure. Efficiency of desorption is reflected in the recovery coefficients published by 3M (1998a), who recommend that each independent laboratory determine their own desorption efficiencies due to slight variations in laboratory procedure. Recovery coefficients are the ratio of recovered to spiked amount of a VOC that was determined for this study using the procedure in Appendix 19c.

6.5 Laboratory Analysis

6.5.1 Selection of the Methodology

The most prevalent techniques for trace organic analysis are gas chromatography (GC), liquid chromatography (LC) and mass spectroscopy (MS) (Segall and Westlin, 1994). In GC, the sample is injected into the instrument, volatized and transported by a carrier gas (mobile phase) into a column. The column has a coating referred to as the stationary phase. Various compounds in the sample have different affinities for the stationary phase resulting in different retention times of these compounds within the column. The compounds leaving the column may then be measured by a detector (Segall and Westlin, 1994).

There are a number of different detectors that may be used in combination with GC but the most common are the flame ionization detector (FID), electron capture detector (ECD) and the mass spectrometer (Wallace, 1993). FID has excellent sensitivity but it is a non-specific detector that would be good for total VOCs but not for individual

compounds (NAS, 1991). ECD is highly selective and typically used to measure halogenated compounds (NAS, 1991). MS has excellent selectivity and sensitivity. The MS can accommodate the same types of compounds as a GC but the analytes must be thermally stable and volatile under GC conditions (NAS, 1991). Hence, the ability of GC/MS to measure trace organic compounds with high selectivity and sensitivity was the primary reason it was used in this study.

The MS detector operates by vaporizing the sample under a high vacuum and then bombarding it with electrons resulting in fragmentation and ionization of the vapor molecules (Segall and Westlin, 1994). These fragmented, ionized molecules are then accelerated into an analyzer that separates them by their mass to charge ratios. This ratio in conjunction with the quantity of each ion yields a fragmentation pattern (mass spectrum) which is used to determine the molecular structure of the compounds. The sensitivity of MS may be further enhanced through its operation in selected ion monitoring (SIM) mode. The SIM mode emphasizes only the major ions characteristic of the mass spectra of a target compound thereby improving the signal to noise ratio (Segall and Westlin, 1994).

6.5.2 Laboratory Analysis Method

The samples were analyzed using GC/MS by the University of Alberta's Department of Public Health Sciences under the supervision of Dr. Ken Froese. The samples were removed from the –50°C freezer and allowed to defrost at room temperature. The samples were than loaded into a Varian® 8200 autosampler that injected 2.0 µL of sample into the gas chromatograph. The gas chromatograph was a Varian® 3800 with a lab alliance column (30m x 0.25mm ID x 1.00 df) manufactured by Chromatix Seperation Sciences. The GC carrier gas was high purity helium and was held at a constant flow rate of 1mL/minute. The detector was a Saturn® 2000 ion trap mass spectrometer with its parameters optimized for each compound (Rose, 1999).

6.5.3 Quality Assurance and Quality Control:

An analytical methodology was developed to maximize the sensitivity, maintain acceptable accuracy and determine the precision (Rose, 1999). Sensitivity was determined from a signal to noise ratio of 4:1 that was defined as the detection limit. The method detection limit (MDL) and limit of quantification (LOQ) were than estimated from this signal to noise ratio using the mean of 7 randomly selected samples, as presented below (Rose, 1999):

$$MDL = \sum_{n=1}^{n=7}\left[\frac{Ce \times 3}{s/n}\right] \Big/ 7 \qquad \textbf{Equation 6}$$

$$LOQ = \sum_{n=1}^{n=7}\left[\frac{Ce \times 10}{s/n}\right] \Big/ 7 \qquad \textbf{Equation 7}$$

where,

Ce = volumetric concentration of VOC, ng/mL
s/n = signal to noise ratio

The target accuracy of ±20% was maintained through the development of an external calibration curve for each target compound. There were control and blank samples performed after every tenth sample to ensure stability of the instrument response. Lastly, there were duplicate samples run to allow for precision to be determined.

6.6 Microenvironmental Survey Questionnaire

6.6.1 Purpose of Questionnaire

A survey questionnaire can serve a variety of purposes in exposure assessment. It can be used as a screening device, as a method to determine events or circumstances related to exposure, or as a method to determine the status of surrogate measures of exposure (NAS, 1991). A well designed and conducted survey can yield precise estimates of multiple parameters used in an exposure assessment. It may be used to obtain information about human time activity patterns, frequency of exposure, source of

exposure, location of exposure, factors affecting exposure concentrations, and physiological and health status (NAS, 1991).

It is common practice to use a questionnaire to obtain information about exposure and it may be the only feasible approach where either the study is retrospective, the exposure is a circumstance or activity, or a cost effective and efficient method is required (Coggon, 1995). U.S. TEAM studies (Wallace, 1986b) employed three different types of questionnaires including a household screening questionnaire, a household characteristics questionnaire and a 24 hour activity recall questionnaire. In the large German study, there was an initial questionnaire to determine household characteristics and general household activities, and a periodic time-activity questionnaire (Seifert et al., 1989). In the Canadian study (Otson and Meek, 1995), a questionnaire was used to obtain data on household characteristics, household occupancy and household activities.

In this study, a questionnaire was designed to obtain information about household characteristics and activities that may influence indoor VOC concentrations. If necessary, results of the questionnaire could be used to help explain anomalous data.

6.6.2 Limitations of Questionnaire

A questionnaire may exhibit a lack of content validity, criterion validity or both (Coggon, 1995; Seifert, 1995; WHO, 1995). It lacks content validity if it does not cover all sources of exposure to the agent of concern. It lacks criterion validity if there is inaccurate or incomplete data collected due to problems with a participant's recall or their understanding of a question (Coggon, 1995; Seifert, 1995; WHO, 1995). The validity of a questionnaire can be tested by comparing data obtained by questionnaire to data collected by other methods, and a lack of validity can be implied by the failure of either repeatability tests or consistency tests (Coggon, 1995; WHO, 1995). However, it has been generally accepted that the pre-testing of a questionnaire eliminates or identifies biases resulting from problems with a questionnaire's validity (Seifert, 1995).

The literature (Coggon, 1995; NAS, 1991; Seifert, 1995; WHO, 1995) recognizes the need for validated standardized questionnaires to avoid duplication and to allow for

cross-study inferences to be made. However, the validity and applicability of a standard questionnaire must be reconsidered in each particular study.

6.6.3 Development of Questionnaire

Development of a questionnaire is a challenging process due to the many different methods, formats, styles and variables to be considered. The National Academy of Science (1991) described the status of questionnaire design:

> "The elements of survey research and questionnaire construction are subtle arts, currently aided by little scientific guidance and, even more, by professional experience and wisdom."

The development of the present study's questionnaire followed the process described in the EPA's *Survey Management Handbook* (EPA, 1983). The content of the questionnaire was determined from the research objectives and potential confounders, and it focused on the major factors that may affect indoor VOC concentrations. These major factors may be categorized into household characteristics and household activities.

The questionnaire was developed using the *Basic Standard Environmental Inventory Questionnaire* (NAS, 1991) as a template, and a literature review (Brooks and Davis, 1992; Otson and Fellin, 1992; Ott, 1990; Wallace et al, 1986b; Wallace et al, 1988; Wallace, 1993) to compose a draft list of topics to include in the questionnaire. The household characteristics that may affect indoor VOC concentrations included gas appliances, attached garages, fireplaces, house age, and heating, ventilation and air conditioning systems. The household activities of interest included renovations, redecorating, and occupations, hobbies and smoking habits.

The first draft of the questionnaire was created from the draft topic list through suggestions provided in the literature, good writing skills, and the investigator's experience in writing documents aimed at the public. EPA (1983) suggests a structure that includes identification and control information, an introduction, instructions, standardized questions and definitions. All of these components were included in the questionnaire with exception of questions being standardized due to a lack thereof. EPA (1983) suggestions employed in wording included that the questions be made clear, and

capable of eliciting objective, unbiased answers. NAS (1991) suggestions employed included concise, explicit questions, a series of questions over a single general question, a reading level tailored to the participants, and memory aids.

The questionnaire was divided into three parts in order to reduce participant burden, reduce potential biases, and to accommodate a two-phase study design. First two parts of the questionnaire completed in the fall were titled Questionnaire: Household Characteristics and Questionnaire: Household Activities. The third part of the questionnaire, titled Winter Questionnaire: Changes to Household Characteristics and Household Activities, was completed in the winter. The participant burden was minimized by making part one a self-applied questionnaire so it could be completed at the participant's leisure, and part three had the household characteristics component modified to minimize repetition with part one. The second part of the questionnaire was conducted after sampling to prevent information it provided on VOC influences resulting in behavioral changes within the participant's home. Lastly, the multiple parts to the questionnaire accommodated any seasonal differences that may exist in household characteristics and activities.

The first draft questionnaire was reviewed by the investigators, a statistician and Capital Health Authority to ensure the following criteria were met: objectives were addressed, individual questions had good form, content, and wording, and it was well organized and formatted (EPA, 1983). The feedback received from reviewers was discussed by the field investigators and used in development of the second draft questionnaire.

A pretest is considered essential and serves to further evaluate the questionnaire's wording, content, format and length (EPA, 1983), and to eliminate biases (Seifert, 1995). The pretest included administering parts one and two of the questionnaire to a sample size of six dwelling units (three in Sherwood Park and three in St. Albert). The pretest was conducted using field procedures planned for the actual survey. Lastly, the field investigators assessed the pretest observations and participant feedback, and used this information to develop a third draft of the questionnaire.

The third draft questionnaire was reviewed by investigators and Capital Health Authority to ensure the aforementioned criteria were met. The feedback received from reviewers was discussed by the field investigators and used in the development of the final draft of the three part Microenvironmental Survey Questionnaire (Appendix 20):

Part 1	Questionnaire: Household Characteristics
Part 2	Questionnaire: Household Activities
Part 3	Winter Questionnaire: Changes to Household Characteristics and Household Activities

6.6.4 Field Procedures for Questionnaire

The three parts of the Microenvironmental Survey Questionnaire were completed in different manners. The first part of the questionnaire was handed out during recruitment (visit 1) and was self-applied. This questionnaire was found to require about 10 to 20 minutes to complete. The participant was able to receive assistance from the "Glossary of Terms", or from the investigators by asking questions during visits or by calling them at phone numbers provided on the front of the questionnaire. When investigators collected the questionnaire during visit 3, they ensured it was complete including both a date and a research identification number.

The second and third parts of the Microenvironmental Survey Questionnaire were completed through an interview process conducted during visit 3 when the samplers were retrieved. These interviews were also found to require about 10 to 20 minutes to complete. The investigators provided assistance where requested and prompts where the participant's response was either incomplete or misguided. Upon completion of the interview questionnaire, the investigator ensured it was complete including both a date and a research identification number. The field procedures are detailed in Appendix 21.

7.0 RESULTS AND DISCUSSION

7.1 Sampling Design

Response rate is the percent of homes that agreed to participate relative to the total number of homes approached. The response rate does not consider the number of times a single home had to be approached in order to obtain consent or refusal to participate. The recruitment campaign had a good response rate from both communities. The response rate was 52% in St. Albert, 40% in Sherwood Park and the overall response rate was 45%. This is comparable to response rates in similar studies, EPA's TEAM studies with response rates of 56% and 49% (Wallace, 1986a and 1986b) and the Canadian study with a response rate of 52% (Otson et al., 1992b). The participant burden was thought to be responsible for the EPA's response rates not being higher (Wallace, 1986a). It is likely that the response rate could be maximized through minimization of participant burden.

In order to prevent the introduction of additional confounders, one attempts to maintain the same participants for the duration of the study. There were three of the original sixty-two participants lost during the study. There was one house that dropped out prior to completion of fall sampling and two houses where the participants had moved out between the fall and winter sampling phases. The participant that dropped out during the sampling phase was simply replaced by another house. Another participant dropped out of the fall phase but the new tenant agreed to participate for the winter phase. The last participant that dropped out after the fall sampling phase had to be replaced by another house on that street for the winter phase. Dropping out of participants between sampling seasons has the potential to affect results of a seasonal comparison but this is highly improbable given that they only constitute 3% of the sample size.

The participant scheduling template was designed to allow representation of exposure in the fall and winter seasons. It was also designed to be very flexible for the participant thereby reducing participant burden. However, there was a tendency for most people to book early in the scheduling period (i.e., first available day), on a weekday in the evening. This is largely an operational limitation of this type of study but one could exercise more control over scheduling to ensure better representation of both the season

and the week. This could be achieved through the development of guidelines on the number of people to be booked on each day of the week during the sampling periods.

7.2 Air Monitoring

The OVM-3500 has been validated but it was considered prudent to monitor the parameters that could theoretically influence sampling. These parameters include temperature, relative humidity and wind speed. Indoor and outdoor air velocities were neither monitored nor reported in this study. Indoor sampling times and conditions are reported in Appendix 22: Field Data Log and outdoor sampling conditions are reported in Appendix 23: Meteorological Summary - Edmonton City Centre Airport. The indoor and outdoor sampling conditions are summarized in Table 4.

Table 4: Environmental Sampling Conditions.

	Temperature (°C)					
	Inside			Outside		
Month	Mean	Min.	Max.	Mean	Min.	Max.
September	21	17	25	13	1	30
October	20	15	24	7	-4	23
January	19	15	24	-13	-29	5
February	18	16	20	-6	-20	7
All	19	15	25	0	-29	30
	Relative Humidity (%)					
	Inside			Outside		
Month	Mean	Min.	Max.	Mean	Min.	Max.
September	48	30	75	---	26	100
October	49	33	66	---	31	100
January	43	23	66	---	23	99
February	31	19	47	---	32	98
All	42	16	75	---	23	100

The OVM-3500 was validated for use at temperatures ranging from –15°C to 40°C (Gagner, 1996). Indoor temperatures were observed to be well within the validated range of 15°C to 25°C. The outdoor temperatures ranged from –29°C to 30°C with the extreme temperatures falling outside of the validated range. However, the mean monthly outdoor temperatures ranging from –13°C to 13°C is suggestive of the outdoor sampling temperatures usually being within the validated range. Further, Gagner (1996) observed

that "the badge sampling rate was not adversely affected during exposures of several hours at temperatures of well below – 30°C."

The OVM-3500 may have reduced VOC adsorption at a relative humidity greater than 50% due to its activated carbon becoming saturated with water resulting in a subsequent reduced sampling rate. The indoor relative humidity ranged from 16% to 75% and the mean monthly indoor relative humidity ranged from 31% to 49%. This is suggestive of most of the indoor relative humidity conditions being within the optimum range of less than 50%. The outdoor relative humidity statistics are highly variable with an observed difference between the daily minimum and maximum ranging from 5% to 60%. The outdoor relative humidity appears to surpass 50% quite frequently. In a validation study (Gagner, 1996) with mean daily relative humidity conditions of 58% to 78%, an outdoor co-location of an OVM-3500 and Summa® canisters was observed to yield consistent accuracy between the two methods and to have 'minimal' effect on precision.

7.3 Treatment of Censored Data

It is not reasonable to estimate statistical parameters from a data set that contains too many values below the detection limit (BDL). There are statistical methods available to 'fill-in' this data that depend on the quality of the data but the mean and variance may be strongly influenced by data below the detection limit (Trivikrama et al., 1991). NIOSH evaluated the method employed in this study to 'fill-in' data and concluded that the use of this method "when much more than half of the data is BDL results in biased or very imprecise estimates of the geometric mean and geometric standard deviation" (Hornung and Reed, 1990). Further, the authors suggest that a better description of the results when more than 50% of the data is BDL is to simply report the percentage of the data that is BDL.

A multitude of VOCs are present in indoor air and using selection criteria described earlier, there were 25 compounds initially targeted for this study. The results revealed a number of these compounds to be either not present or present at

concentrations that were below detection limits. The targeted compounds listed in Table 5 below show the percentage of samples that were below detection limits.

Table 5: Proportion of samples below the detection limits.

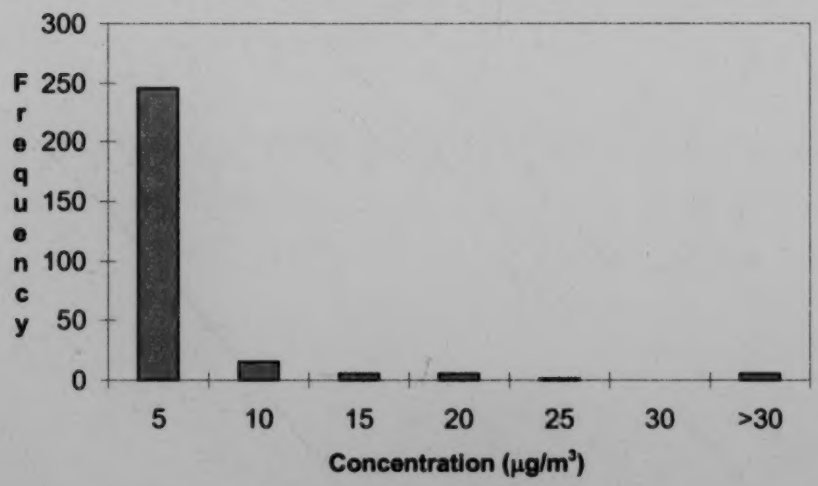
Volatile Organic Compound	Method DL (ug/m3)	Samples Below Detection Limits (%)		
		Fall	Winter	Total
1,1,1-Trichloroethane	0.2	0.0	0.0	0.0
Ethylbenzene	0.2	0.0	0.0	0.0
1,2,4-Trimethylbenzene	---	0.0	0.0	0.0
Toluene	0.2	0.0	0.7	0.4
(m+p) xylene	0.2	0.0	0.7	0.4
o-xylene	0.3	0.0	2.1	1.1
1,3,5-Trimethylbenzene	0.2	6.6	0.0	3.2
Carbon Tetrachloride	0.4	5.8	4.2	5.0
Chloroform	0.3	11	0.0	5.4
Chlorobenzene	0.1	8.0	7.7	7.9
Naphthalene	0.4	12	9.2	11
Tetrachloroethylene	0.5	26	13	19
Benzene	1.3	42	7.0	24
Trichloroethylene	0.4	21	54	38
1,4-Dichlorobenzene	0.2	42	56	49
Styrene	0.4	54	56	55
Cumene	0.2	77	71	74
1,2-Dichloroethane	---	78	86	82
1,1-Dichloroethane	0.6	100	70	85
Bromoform	---	73	96	85
1,2,3-Trichloropropane	---	96	99	98
1,1,2-Trichloroethane	---	99	97	98
1,3-Dichlorobenzene	---	98	99	99
1,1,2,2-Tetrachloropropane	---	100	100	100
Hexachlorobutadiene	---	100	100	100

The remaining data, data analysis and interpretation presented in this study address a shorter list of fifteen target VOCs. Compounds that could not be identified, due to methodological limitations, were excluded early in the study. The compounds that could not be quantified due to an insufficient signal to noise ratio of less than 4:1 were reported as BDL (Rose, 1999) and are referred to as 'censored' data (Helsel, 1990). Lastly, compounds that had a signal to noise ratio of greater than 4:1 were quantified and reported in volumetric concentrations of nanograms per milliliter (ng/mL) of carbon disulfide. In Table 5, this includes the first 16 VOCs with the exception of 1,2,4-

trimethylbenzene for which the sampling rate is unknown (3M, 1998a). These fifteen target compounds have data sets that are consistent with recommendations made by NIOSH (Hornung and Reed, 1990).

The determination of a central measure of VOC concentrations required the censored data to be replaced with numerical values. Environmental quality data are usually positively skewed or have lognormal distributions (Helsel, 1990). There are a number of statistical methods that may be employed to 'fill-in' censored data for lognormal distributions. NIOSH (Hornung and Reed, 1990) evaluated several commonly applied methods including the maximum likelihood method, the half detection limit method (DL/2), and a method that takes the limit of detection over the square root of two. The maximum likelihood method was the best overall method but the 'DL/2' method produced comparable results when the data was highly skewed. All of the data collected in this study had a highly skewed lognormal distribution, as observed in the characteristic histogram of 1,1,1-trichloroethane data in Figure 8. This made the selection of the 'DL/2' method an attractive one due to its simplicity. However, one should recognize that this method implicitly assumes that data below the detection limit follows a normal distribution and results in a biased estimation of the standard deviation (Trivikrama et al., 1991).

Figure 8: Histogram of indoor and outdoor 1,1,1-trichloroethane data.



The 'DL/2' method was employed for compounds that were reported by the laboratory as BDL and for compounds whose concentrations were observed to fall below the mean concentration of the trip blanks. The concentration values that fell below the value of the trip blank were considered to be an artifact of the sampling methodology and thus effectively BDL. The data that was either censored or considered an artifact was filled in with values calculated by dividing the method detection limit (MDL) by two.

Subsequent to filling in all of the necessary numerical data, the VOC concentration measured in solvent had to be transposed to the VOC concentration in air (Ca). This was achieved by employing the following equation (after 3M, 1998a):

$$Ca = \frac{(Ce - Ctb) \times Ve \times A}{r \times t} \qquad \textbf{Equation 8}$$

where,

Ce = concentration in solvent extract, ng/mL
Ctb = concentration in trip blank's solvent extract, ng/mL
Ve = volume of solvent used for extraction, mL
A = 3M calculation constant, 10^3 minutes/m^3
r = 3M recovery coefficient, ratio
t = sampling time, minutes

The measured variable Ce is the volumetric VOC concentration in carbon disulfide as reported by the analytical laboratory (Appendix 24). The variable Ctb is a quality assurance and quality control parameter used to determine the background VOC contamination (Appendix 25). The variable Ve is the measured volume of solvent used in extraction. The constant A takes into consideration the PSD's different sampling rates for each VOC and is provided by 3M (Appendix 25). The variable r is a recovery coefficient that allows one to account for the efficiency with which each VOC may be extracted from the PSD and is also provided by 3M (Appendix 25). The measured variable t is sampling time reported by the field investigators in the Field Data Log (Appendix 22).

7.4 Data Analysis

There are frequently inappropriate statistical measures employed to summarize environmental quality data such as air quality data (Helsel, 1990). Environmental quality data usually have a lognormal distribution due to many values being very close to zero especially data that are partially censored. A few data points in the upper tail of the distribution may result in a significant bias of the mean and standard deviation making these statistics less desirable measures of central tendency and variability. The recommended measures of central tendency and variability for lognormal distributions respectively are the median and the interquartile range (IQR).

The median and IQR are not strongly affected by a few very low or very high data points. The median is the 50^{th} percentile and the IQR is the difference of the 75^{th} and 25^{th} percentiles. The geometric mean when the logarithms are symmetric is an estimate of the median. NIOSH recommends that the geometric mean and geometric standard deviation be employed for data sets with lognormal distributions (Hornung and Reed, 1990). Many studies describing lognormal distributions continue to use the mean and standard deviation as statistical measures (Wallace, 1991a and Otson and Fellin, 1992). Statistical tests employed in this study also require the use of the mean and standard deviation in analyses (Jhandri, 1999). This study reports the measures of central tendency and variability using the recommended method of median and IQR but some results are also presented using the mean and standard deviation to allow comparison of its results to other studies.

Data analyses were performed to allow the research objectives to be achieved. As a reminder, the research objectives were to determine concentrations of the targeted VOCs, to determine if a difference exists in the VOC concentrations between Sherwood Park and St. Albert and to establish the indoor to outdoor VOC ratios. The data analyses involved the following components:

1. histograms plotted to determine data distributions,
2. descriptive statistics presented to summarize the data,
3. statistical tests performed to determine any significant differences,
4. VOC ratios presented to demonstrate the magnitude of any differences and

5. comparative table presented to provide an international perspective.

It was important to establish the data distribution in order to describe the data, to determine appropriate statistical descriptors, and to determine whether the normal distribution assumption required for a parametric t-test was met. All of the data was observed in histograms, example in Figure 8, to be a positively skewed or lognormal distribution as the aforementioned literature had suggested.

As the data has a lognormal distribution, it should be transposed prior to applying parametric tests that assume a normal distribution (Jhangri, 1999). The data was transposed, by taking the natural log, and the resultant histograms (Appendix 26) confirmed that this normalized the data set. For six of the target compounds, the histogram shows a frequency in one interval that does not appear to follow the normal distribution. These 'peaks' are a result of a relatively high proportion of the samples qualifying as censored data and thus being replaced with a number that falls within the 'peak' interval. The appropriate parametric t-tests were applied to the transposed data to test a variety of null hypotheses aimed at achieving the research objectives.

7.4.1 Indoor to Outdoor Comparison of VOC Levels

There were numerous studies presented within section 2.0 demonstrating that VOC levels are normally higher indoors than outdoors. A summary of indoor and outdoor VOC concentrations (Tables 6 to 9) demonstrate that this situation also appears to hold true within St. Albert and Sherwood Park. Paired t-tests (α = 5%) were conducted to determine whether the difference between indoor and outdoor VOC levels was significant. The results of these tests (Appendix 27) show that indoor levels are significantly higher than outdoor levels for most target compounds. There is no significant difference observed for carbon tetrachloride or trichloroethylene in either season or for chlorobenzene in the fall season. A significant difference is suggestive of indoor sources of these compounds whereas the lack of a significant difference is suggestive of predominantly outdoor sources contributing to indoor levels.

Table 6: St. Albert residential VOC concentrations ($\mu g/m^3$) in fall with the significant indoor to outdoor differences highlighted ($\alpha = 0.05$, n = 30).

Volatile Organic Compounds	St. Albert in Fall					
	Indoor			Outdoor		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	1.3	2.0	9.3	0.1	0.1	0.8
1,1,1-Trichloroethane	1.1	2.1	160	0.4	0.3	1.4
Carbon Tetrachloride	0.8	0.3	2.4	0.8	0.3	1.2
Benzene	0.6	6.7	20	1.0	5.7	18
Trichloroethylene	0.2	0.4	2.7	0.2	0.3	1.6
Toluene	6.2	19	51	0.3	8.1	76
Tetrachloroethylene	0.8	2.2	45	0.3	0.6	2.6
Chlorobenzene	0.0	0.1	0.4	0.0	0.1	0.4
Ethylbenzene	2.4	2.9	180	0.7	1.6	5.1
(m+p) xylene	8.1	12	620	2.9	6.9	18
o-xylene	2.9	3.8	220	0.9	2.5	6.2
Naphthalene	0.5	0.8	8.8	0.3	0.4	1.6
1,3,5-Trimethylbenzene	0.7	1.0	150	0.1	0.8	2.2
1,4-Dichlorobenzene	0.1	0.3	18	0.1	0.0	5.6
Styrene	0.5	0.8	11	0.2	0.0	0.7

IQR = interquartile range

Table 7: Sherwood Park residential VOC concentrations ($\mu g/m^3$) in fall with the significant indoor to outdoor differences highlighted ($\alpha = 0.05$, n = 32).

Volatile Organic Compounds	Sherwood Park in Fall					
	Indoor			Outdoor		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	0.8	1.4	4.2	0.1	0.0	9.7
1,1,1-Trichloroethane	1.9	4.1	15	0.4	0.4	2.7
Carbon Tetrachloride	0.7	0.5	1.5	0.8	0.3	1.3
Benzene	0.6	5.0	16	0.6	0.3	11
Trichloroethylene	0.3	0.3	2.1	0.2	0.2	1.0
Toluene	10.6	20.0	56	0.1	1.5	17
Tetrachloroethylene	0.9	1.9	39	0.3	0.3	7.0
Chlorobenzene	0.1	0.1	0.4	0.0	0.0	0.4
Ethylbenzene	2.7	3.3	33	0.5	0.8	3.1
(m+p) xylene	9.4	10.2	77	1.5	2.7	12
o-xylene	3.3	3.2	21	0.6	0.9	4.3
Naphthalene	0.4	0.8	1.8	0.2	0.0	1.6
1,3,5-Trimethylbenzene	0.9	1.1	7.5	0.1	0.1	5.7
1,4-Dichlorobenzene	0.3	0.6	4.2	0.1	0.0	0.6
Styrene	0.6	0.7	3.2	0.2	0.0	2.2

IQR = interquartile range

Table 8: St. Albert residential VOC concentrations ($\mu g/m^3$) in winter with the significant indoor to outdoor differences highlighted ($\alpha = 0.05$, n = 30).

Volatile Organic Compounds	St. Albert in Winter					
	Indoor			Outdoor		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	1.5	2.7	7.8	0.1	0.3	1.5
1,1,1-Trichloroethane	1.1	2.4	54	0.4	0.4	2.3
Carbon Tetrachloride	0.7	0.3	2.0	0.6	0.2	2.2
Benzene	2.4	2.6	11	0.8	1.8	4.6
Trichloroethylene	0.2	0.1	2.7	0.2	0.1	15
Toluene	9	10	87	3.8	7	31
Tetrachloroethylene	1.0	1.8	21	0.4	0.4	2.2
Chlorobenzene	0.0	0.0	0.3	0.0	0.0	3.6
Ethylbenzene	1.8	1.7	34	1.2	1.2	5.2
(m+p) xylene	7.4	7	140	3.5	5.3	13
o-xylene	2.8	2.4	44	1.3	1.7	4.9
Naphthalene	0.7	1.3	2.9	0.2	1.0	2.7
1,3,5-Trimethylbenzene	1.0	1.1	25	0.4	0.5	1.5
1,4-Dichlorobenzene	0.1	0.2	46	0.1	0.0	0.3
Styrene	0.9	1.0	5.2	0.2	0.0	0.2

IQR = interquartile range

Table 9: Sherwood Park residential VOC concentrations ($\mu g/m^3$) in winter with the significant indoor to outdoor differences highlighted ($\alpha = 0.05$, n = 32).

Volatile Organic Compounds	Sherwood Park in Winter					
	Indoor			Outdoor		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	0.9	1.4	11	0.1	0.3	2.6
1,1,1-Trichloroethane	1.6	3.0	19	0.4	0.4	1.4
Carbon Tetrachloride	0.7	0.3	2.0	0.6	0.2	6.3
Benzene	1.8	3.0	17	0.8	1.8	5.3
Trichloroethylene	0.2	0.1	3.7	0.2	0.1	1.0
Toluene	7.6	13.5	54	3.8	7.2	24
Tetrachloroethylene	0.8	0.9	290	0.4	0.4	1.7
Chlorobenzene	0.0	0.0	0.2	0.0	0.0	3.3
Ethylbenzene	1.5	1.4	11	1.2	1.2	4.2
(m+p) xylene	5.6	4.7	44	3.5	5.3	6.8
o-xylene	2.1	1.7	21	1.3	1.7	3.0
Naphthalene	0.5	1.0	2.8	0.2	1.0	2.2
1,3,5-Trimethylbenzene	0.8	0.6	5.3	0.4	0.5	0.9
1,4-Dichlorobenzene	0.1	0.3	3.4	0.1	0.0	0.3
Styrene	0.7	0.8	3.4	0.2	0.0	1.4

IQR = interquartile range

7.4.2 Seasonal Comparison of VOC Levels

There were a variety of studies presented within section 6.2 that suggested both indoor and outdoor seasonal differences. The primary reason suggested for seasonal differences indoors has been increased fresh air ventilation during the warmer seasons. In Tables 10 to 13, results are presented in a format that allows the comparison of seasonal VOC levels in both communities. There were paired t-tests (α = 5%) performed to determine whether the difference between fall and winter VOC levels was significant for individual compounds. The results of these tests (Appendix 28) show that for most target compounds the indoor and outdoor seasonal differences are insignificant. This brings into question the observation in the Canadian study that the highest indoor VOC levels in the 'prairie provinces' occur in the fall season (Fellin and Otson, 1993). It also brings into question the observation in Alberta that urban centers have the highest outdoor benzene levels in the winter (Dann and Wang, 1995). However, it is important to remember that both of these studies had differences in both their design and data analysis methods.

The parametric t-tests looking at seasonal differences did detect some significant differences in indoor VOC levels (Tables 10 to 13). Indoor chloroform levels were higher in winter than fall. This could be due to a combination of the predominantly indoor source of chloroform, a chlorinated water supply, and reduced natural ventilation rates during the colder winter season. On the contrary, the indoor trichloroethylene, ethylbenzene and (m+p) xylene levels were lower in the winter than in the fall. This is suggestive of an outdoor source of these compounds contributing to indoor levels through infiltration from increased natural ventilation rates during warmer days in the fall season. Lastly, there were seasonal differences detected in the indoor 1,4-dichlorobenzene and indoor and outdoor styrene levels, but one should place little confidence in these results due to the high proportion of samples, 49% and 55% respectively, that were below the detection limits.

Table 10: St. Albert residential indoor VOC concentrations ($\mu g/m^3$) with the significant fall to winter differences highlighted ($\alpha = 0.05$, n = 30).

Volatile Organic Compounds	St. Albert Indoors					
	Fall			Winter		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	1.3	2.0	9.3	1.5	2.7	7.8
1,1,1-Trichloroethane	1.1	2.1	160	1.1	2.4	54
Carbon Tetrachloride	0.8	0.3	2.4	0.7	0.3	2.0
Benzene	0.6	6.7	20	2.4	2.6	11
Trichloroethylene	0.2	0.4	2.7	0.2	0.1	2.7
Toluene	6.2	19	51	8.9	9.7	87
Tetrachloroethylene	0.8	2.2	45	1.0	1.8	21
Chlorobenzene	0.0	0.1	0.4	0.0	0.0	0.3
Ethylbenzene	2.4	2.9	180	1.8	1.7	34
(m+p) xylene	8.1	12	620	7.4	6.8	140
o-xylene	2.9	3.8	220	2.8	2.4	44
Naphthalene	0.5	0.8	8.8	0.7	1.3	2.9
1,3,5-Trimethylbenzene	0.7	1.0	150	1.0	1.1	25
1,4-Dichlorobenzene	0.1	0.3	18	0.1	0.2	46
Styrene	0.5	0.8	11	0.9	1.0	5.2

IQR = interquartile range

Table 11: St. Albert residential outdoor VOC concentrations ($\mu g/m^3$) with the significant fall to winter differences highlighted ($\alpha = 0.05$, n = 30).

Volatile Organic Compounds	St. Albert Outdoors					
	Fall			Winter		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	0.1	0.1	0.8	0.1	0.3	1.5
1,1,1-Trichloroethane	0.4	0.3	1.4	0.4	0.4	2.3
Carbon Tetrachloride	0.8	0.3	1.2	0.6	0.2	2.2
Benzene	1.0	5.7	18	0.8	1.8	4.6
Trichloroethylene	0.2	0.3	1.6	0.2	0.1	15
Toluene	0.3	8.1	76	3.8	7.2	31
Tetrachloroethylene	0.3	0.6	2.6	0.4	0.4	2.2
Chlorobenzene	0.0	0.1	0.4	0.0	0.0	3.6
Ethylbenzene	0.7	1.6	5.1	1.2	1.2	5.2
(m+p) xylene	2.9	6.9	18	3.5	5.3	13
o-xylene	0.9	2.5	6.2	1.3	1.7	4.9
Naphthalene	0.3	0.4	1.6	0.2	1.0	2.7
1,3,5-Trimethylbenzene	0.1	0.8	2.2	0.4	0.5	1.5
1,4-Dichlorobenzene	0.1	0.0	5.6	0.1	0.0	0.3
Styrene	0.2	0.0	0.7	0.2	0.0	0.2

IQR = interquartile range

Table 12: Sherwood Park residential indoor VOC concentrations ($\mu g/m^3$) with the significant fall to winter differences highlighted ($\alpha = 0.05$, n = 32).

Volatile Organic Compounds	Sherwood Park Indoors					
	Fall			Winter		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	0.8	1.4	4.2	0.9	1.4	11
1,1,1-Trichloroethane	1.9	4.1	15	1.6	3.0	19
Carbon Tetrachloride	0.7	0.5	1.5	0.7	0.3	2.0
Benzene	0.6	5.0	16	1.8	3.0	17
Trichloroethylene	0.3	0.3	2.1	0.2	0.1	3.7
Toluene	11	20	56	7.6	14	54
Tetrachloroethylene	0.9	1.9	39	0.8	0.9	290
Chlorobenzene	0.1	0.1	0.4	0.0	0.0	0.2
Ethylbenzene	2.7	3.3	33	1.5	1.4	11
(m+p) xylene	9.4	10	77	5.6	4.7	44
o-xylene	3.3	3.2	21	2.1	1.7	21
Naphthalene	0.4	0.8	1.8	0.5	1.0	2.8
1,3,5-Trimethylbenzene	0.9	1.1	7.5	0.8	0.6	5.3
1,4-Dichlorobenzene	0.3	0.6	4.2	0.1	0.3	3.4
Styrene	0.6	0.7	3.2	0.7	0.8	3.4

IQR = interquartile range

Table 13: Sherwood Park residential outdoor VOC concentrations ($\mu g/m^3$) with the significant fall to winter differences highlighted ($\alpha = 0.05$, n = 32).

Volatile Organic Compounds	Sherwood Park Outdoors					
	Fall			Winter		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	0.1	0.0	9.7	0.1	0.2	2.6
1,1,1-Trichloroethane	0.4	0.4	2.7	0.4	0.3	1.4
Carbon Tetrachloride	0.8	0.3	1.3	0.5	0.2	6.3
Benzene	0.6	0.3	11	0.6	1.1	5.3
Trichloroethylene	0.2	0.2	1.0	0.2	0.0	1.0
Toluene	0.1	1.5	17	0.8	5.2	24
Tetrachloroethylene	0.3	0.3	7.0	0.3	0.3	1.7
Chlorobenzene	0.0	0.0	0.4	0.0	0.0	3.3
Ethylbenzene	0.5	0.8	3.1	0.3	0.4	4.2
(m+p) xylene	1.5	2.7	12	1.1	1.6	6.8
o-xylene	0.6	0.9	4.3	0.5	0.6	3.0
Naphthalene	0.2	0.0	1.6	0.2	0.6	2.2
1,3,5-Trimethylbenzene	0.1	0.1	5.7	0.2	0.3	0.9
1,4-Dichlorobenzene	0.1	0.0	0.6	0.1	0.0	0.3
Styrene	0.2	0.0	2.2	0.2	0.0	1.4

IQR = interquartile range

7.4.3 Community Comparison of VOC Levels

The pooled fall and winter data (Tables 14 and 15) were used to test the hypothesis that no significant difference exists between residential VOC levels in Sherwood Park and St. Albert. A two sample t-test for means ($\alpha = 5\%$) was conducted to determine if there is a significant difference in VOC levels between these two communities. As t-tests assume either equal or unequal variances, a hypothesis of equal variances was tested (Appendix 29) using the two-tailed F-test ($\alpha = 5\%$) to determine the appropriate t-test. The t-tests (Appendix 30) found no significant difference in the concentration of all indoor and most outdoor compounds between these communities. Thus, one must reject the null hypothesis that there is a significant difference between indoor VOC levels in Sherwood Park and St. Albert. This also supports the findings of other studies, cited within the Background Information, that the predominant source of indoor air pollutants is from indoor sources.

Table 14: Residential indoor VOC concentrations ($\mu g/m^3$) with the significant St. Albert (n = 60) to Sherwood Park (n = 64) differences highlighted ($\alpha = 0.05$).

Volatile Organic Compounds	Indoor					
	St. Albert			Sherwood Park		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	1.4	2.4	9.3	0.9	1.6	11
1,1,1-Trichloroethane	1.1	2.5	160	1.8	3.7	19
Carbon Tetrachloride	0.7	0.3	2.4	0.7	0.4	2.0
Benzene	2.0	3.4	20	1.5	3.7	17
Trichloroethylene	0.2	0.2	2.7	0.2	0.2	3.7
Toluene	8.6	17.0	87	8.4	16.0	56
Tetrachloroethylene	0.9	2.1	45	0.8	1.6	290
Chlorobenzene	0.0	0.0	0.4	0.0	0.0	0.4
Ethylbenzene	2.0	2.0	180	2.2	2.7	33
(m+p) xylene	7.4	7.8	620	7.1	9.2	77
o-xylene	2.8	2.8	220	2.8	2.4	21
Naphthalene	0.6	1.1	8.8	0.4	0.9	2.8
1,3,5-Trimethylbenzene	0.9	1.0	150	0.8	0.9	7.5
1,4-Dichlorobenzene	0.1	0.3	46	0.1	0.5	4.2
Styrene	0.7	0.9	11	0.7	0.7	3.4

IQR = interquartile range

Table 15: Residential outdoor VOC concentrations ($\mu g/m^3$) with the significant St. Albert (n = 60) to Sherwood Park (n = 64) differences highlighted ($\alpha = 0.05$).

Volatile Organic Compounds	Outdoor					
	St. Albert			Sherwood Park		
	Median	IQR	Maximum	Median	IQR	Maximum
Chloroform	0.1	0.2	1.5	0.1	0.2	9.7
1,1,1-Trichloroethane	0.4	0.3	2.3	0.4	0.3	2.7
Carbon Tetrachloride	0.7	0.4	2.2	0.6	0.4	6.3
Benzene	0.8	2.7	18	0.6	0.9	11
Trichloroethylene	0.2	0.3	15	0.2	0.1	1.0
Toluene	1.4	8.0	76	0.1	3.1	24
Tetrachloroethylene	0.3	0.4	2.6	0.3	0.3	7.0
Chlorobenzene	0.0	0.1	3.6	0.0	0.0	3.3
Ethylbenzene	0.9	1.5	5.2	0.4	0.5	4.2
(m+p) xylene	3.1	5.2	18	1.4	1.9	12
o-xylene	1.1	2.0	6.2	0.5	0.7	4.3
Naphthalene	0.2	0.5	2.7	0.2	0.5	2.2
1,3,5-Trimethylbenzene	0.4	0.7	2.2	0.2	0.3	5.7
1,4-Dichlorobenzene	0.1	0.0	5.6	0.1	0.0	0.6
Styrene	0.2	0.0	0.7	0.2	0.0	2.2

IQR = interquartile range

Parametric t-tests looking at community differences did detect some significant differences in outdoor VOC levels. The outdoor concentrations of benzene, toluene, ethylbenzene, (m+p) xylene, o-xylene (BTEX compounds) and 1,3,5-trimethylbenzene were significantly higher in St. Albert than in Sherwood Park (Table 15). The outdoor concentration ratios of St. Albert to Sherwood Park (Table 16) reveal ethylbenzene, (m+p) xylene, o-xylene and 1,3,5-trimethylbenzene to be about two times higher, benzene to be 1.3 times higher and toluene to be about fifteen times higher in St. Albert. Although, specific sources of these compounds could not be determined from this study, Alberta Environmental Protection (1998) reported that the major source of total hydrocarbons in urban centers is motor vehicle emissions. The major parameters affecting the dispersion of air pollutants are atmospheric and topographical conditions, and it is unlikely that the atmospheric conditions vary much between two communities in such close proximity. However, it is possible that these higher BTEX levels could be the result of greater motor vehicle emissions in close proximity to St. Albert. This difference could also be a result

of the topography, with the entire community of St. Albert situated in a valley encompassing the Sturgeon River, or possibly a combination of these two parameters.

Table 16: St. Albert to Sherwood Park median VOC concentration ratios with the significant differences highlighted ($n_{St.\ Albert} = 60$, $n_{Sherwood\ Park} = 64$, $\alpha = 0.05$).

Volatile Organic Compounds	St. Albert : Sherwood Park	
	Indoors	Outdoors
Chloroform	1.7	1.0
1,1,1-Trichloroethane	0.6	1.0
Carbon Tetrachloride	1.0	1.1
Benzene	1.4	1.3
Trichloroethylene	0.9	1.0
Toluene	1.0	15
Tetrachloroethylene	1.0	1.2
Chlorobenzene	1.0	1.0
Ethylbenzene	0.9	2.5
(m+p) xylene	1.0	2.3
o-xylene	1.0	2.1
Naphthalene	1.3	1.3
1,3,5-Trimethylbenzene	1.1	2.4
1,4-Dichlorobenzene	0.9	1.0
Styrene	1.0	1.0

7.4.4 Residential VOC Levels

The seasonal and community data were pooled to establish the current baseline residential VOC levels within the urban Capital Health Region. These data are presented (Tables 17 and 18) using the arithmetic mean and its associated standard deviation (σ), the median and its associated IQR and the maximum. This approach allows one to observe differences between the different measures of central tendency and variation, and to compare results to other studies using either of the statistical descriptors. The results encompass all of the limitations in the study including the fact that they do not express the seasonal differences in some indoor VOC levels or geographical differences in some outdoor VOC levels. However, given the current state of technology, they represent a reasonable measure of residential VOC levels within the Capital Health Region.

Table 17: St. Albert and Sherwood Park (n = 124) residential indoor VOC concentrations (μg/m^3).

Volatile Organic Compounds	St. Albert and Sherwood Park Indoor				
	Mean	Median	IQR	σ	Maximum
Chloroform	1.8	1.0	1.8	2.0	11
1,1,1-Trichloroethane	5.6	1.4	3.3	16	160
Carbon Tetrachloride	0.8	0.7	0.4	0.4	2.4
Benzene	3.4	1.5	3.7	4.1	20
Trichloroethylene	0.4	0.2	0.2	0.5	3.7
Toluene	14	8.4	16	16	87
Tetrachloroethylene	4.9	0.9	1.9	27	290
Chlorobenzene	0.1	0.0	0.0	0.1	0.4
Ethylbenzene	4.9	2.1	2.2	17	180
(m+p) xylene	17	7.3	8.8	57	620
o-xylene	6.0	2.8	2.6	20	220
Naphthalene	0.8	0.5	0.9	1.1	8.8
1,3,5-Trimethylbenzene	2.6	0.9	0.9	13	150
1,4-Dichlorobenzene	1.0	0.1	0.4	4.4	46
Styrene	1.0	0.7	0.9	1.4	11

IQR = interquartile range
σ = standard deviation

Table 18: St. Albert and Sherwood Park (n = 124) residential outdoor VOC concentrations (μg/m^3).

Volatile Organic Compounds	St. Albert and Sherwood Park Outdoor				
	Mean	Median	IQR	σ	Maximum
Chloroform	0.3	0.1	0.2	0.9	9.7
1,1,1-Trichloroethane	0.5	0.4	0.3	0.4	2.7
Carbon Tetrachloride	0.7	0.7	0.4	0.6	6.3
Benzene	2.0	0.6	1.5	2.8	18
Trichloroethylene	0.4	0.2	0.2	1.3	15
Toluene	4.7	0.2	6.9	8.9	76
Tetrachloroethylene	0.6	0.3	0.4	0.8	7.0
Chlorobenzene	0.1	0.0	0.0	0.4	3.6
Ethylbenzene	1.0	0.5	1.1	1.1	5.2
(m+p) xylene	3.1	1.7	4.1	3.5	18
o-xylene	1.2	0.6	1.3	1.3	6.2
Naphthalene	0.5	0.2	0.5	0.5	2.7
1,3,5-Trimethylbenzene	0.5	0.2	0.5	0.6	5.7
1,4-Dichlorobenzene	0.2	0.1	0.0	0.5	5.6
Styrene	0.3	0.2	0.0	0.3	2.2

IQR = interquartile range
σ = standard deviation

The last research objective was to determine the indoor to outdoor concentration ratios (Table 19). It was demonstrated earlier that a significant difference between indoor and outdoor VOC levels was observed. These ratios have values ranging from one for compounds with an insignificant difference to a maximum of 92 for compounds with a significant difference. Overall, the indoor VOC concentrations were observed to be approximately 2 to 11 times the outdoor VOC concentrations within Capital Health Region. This is comparable to the results of the TEAM studies that observed mean indoor VOC levels to be 2 to 10 times the outdoor VOC levels for nearly all prevalent VOCs (Wallace, 1991). The exception was toluene that was observed to have an outdoor concentration that was about fifteen times lower in Sherwood Park than St. Albert (Table 15), resulting in an indoor to outdoor ratio in Sherwood Park that was fifteen times higher in Sherwood Park (Table 19). Again, the reason for this difference in outdoor toluene levels cannot be determined by the present research.

Table 19: Indoor to outdoor median residential VOC concentration ratios for St. Albert (n = 60), Sherwood Park (n = 64) and both communities pooled (n = 124) with significant indoor to outdoor differences highlighted ($\alpha = 0.05$).

Volatile Organic Compounds	Indoor : Outdoor		
	St. Albert	Sherwood Park	Pooled
Chloroform	11	6.9	8.6
1,1,1-Trichloroethane	2.8	4.3	3.0
Carbon Tetrachloride	1.0	1.1	1.1
Benzene	2.4	2.4	2.5
Trichloroethylene	1.0	1.2	1.0
Toluene	6.3	92	77
Tetrachloroethylene	2.8	3.3	3.1
Chlorobenzene	1.0	1.0	1.0
Ethylbenzene	2.2	5.8	3.3
(m+p) xylene	2.4	5.3	4.3
o-xylene	2.5	5.3	4.1
Naphthalene	2.3	2.4	2.4
1,3,5-Trimethylbenzene	2.2	4.9	3.6
1,4-Dichlorobenzene	1.0	1.2	1.0
Styrene	3.5	3.3	3.0

7.4.5 International Comparison of Indoor VOC Levels

Indoor baseline VOC levels observed within Capital Health Region were compared to the results of similar studies conducted elsewhere (Table 20). The mean or median VOC levels seem to demonstrate comparable results for individual compounds given the spatial, temporal and methodological differences in each of the studies. The other studies were all large studies with 300 to 800 homes sampled in Canada, United States, West Germany and the Netherlands in the mid 1980s to the early 1990s. These studies employed different sampling times and methods, different laboratory analysis methods and different reporting methods as observed in the table below. It is the complex interaction of these differences that on a balance of probabilities is likely responsible for the observed differences. However, despite all of the differences in these studies, there is no more than one order of magnitude difference between the measures of central tendency suggesting that the indoor VOC levels are likely comparable in all of these countries.

Table 20: International residential indoor VOC concentrations ($\mu g/m^3$).

Volatile Organic Compound	Indoor					
	Mean				Median	
	CHR[1]	Canada[2]	U.S.A.[3]	German[3]	Dutch[3]	CHR[1]
Chlorinated Hydrocarbons						
Carbon Tetrachloride	0.8	NA[4]	NA	NA	NA	0.7
Chlorobenzene	0.1	NA	NA	NA	NA	0.0
Chloroform	1.8	4.1	3	NA	NA	1.0
1,1,1-trichloroethane	5.6	NA	52	9	NA	1.4
trichloroethylene	0.4	1.4	6	11	<2	0.2
perchloroethylene	4.9	5.1	16	14	<2	0.9
p-Dichlorobenzene	1.0	16	25	14	1	0.1
Aromatics						
Benzene	3.4	7.4	16	10	6	1.5
Styrene	1.0	2.9	3	2	NA	0.7
Ethylbenzene	4.9	11	9	10	2	2.1
o-Xylene	6.0	7.6	9	7	105[5]	2.8
m,p-Xylene	17	26	26	23	---	7.3
Napthalene	0.8	NA	NA	NA	NA	0.5
Toluene	14	36	NA	84	35	8.4
1,3,5-Trimethylbenzene	2.6	NA	NA	NA	NA	0.9

1. Current research results within the Capital Health Region (CHR).
2. Otson, Fellin and Whitmore, 1992b.
3. As cited in Wallace, 1991a.
4. NA indicates these compounds were not targeted for a particular study.
5. All xylene isomers reported as o-xylene.

7.5 Quality Assurance and Quality Control

7.5.1 Air Sampling Quality Assurance and Quality Control

Air sampling quality assurance and quality control procedures discussed in section 6.0 involved following air sampling procedures and performance of trip blanks and field replicates. Results of trip blank samples (Appendix 31) suggest that background contamination existed on PSDs for all targeted compounds except possibly carbon tetrachloride which was 100% BDL. The level of contamination on PSDs for the various compounds was variable ranging from BDL to 20 $\mu g/m^3$. Generally, mean background contamination on the PSDs was less than 2 $\mu g/m^3$ for target compounds with the exception of toluene at 10$\mu g/m^3$. The background contamination was corrected for by deducting background levels from levels measured in the microenvironmental samples (Equation 8).

Sampling precision was determined from the field replicates using the relative standard deviation (RSD) or coefficient of variation as recommended by the EPA (1994). This determination of the RSD involves the following calculation:

$$RSD = 100 \times \left[\frac{\text{standard deviation of replicates}}{\text{mean of replicates}} \right] \qquad \textbf{Equation 9}$$

The median indoor sampling precision ranged from <1% to 51% and the maximum ranged from 17% to 130% (Appendix 32). The median outdoor sampling precision ranged from <1% to 127% and the maximum ranged from <1% to 230% (Appendix 33). The current study's variability in precision is consistent with other studies that also reported a variability in precision (Gagner, 1996). Gagner's validation study (1996) observed benzene measures greater than 5 $\mu g/m^3$ vary up to ±25% while those less than 5 $\mu g/m^3$ vary up to ±50%, and toluene measures above 10 $\mu g/m^3$ varied up to ±25% and those below 10 $\mu g/m^3$ varied up to ±90%. Gagner concluded that this variability in precision was primarily due to variation in background contamination of both PSDs and carbon disulfide batches. The better precision indoors is likely a result of indoor VOC

concentrations 2 to 11 times higher than outdoors usually exceeding background levels. Hence, one may conclude that the indoor and outdoor sampling precision appeared to be dependent upon the target compound and the level of background contamination.

7.5.2 Laboratory Desorption Quality Assurance and Quality Control

Quality assurance and quality control protocols used in laboratory desorption discussed in section 6.0 involved use of high purity solvent, accurate and precise measurement of solvent, determination of desorption efficiency and adhering to laboratory procedures. A test of supplier's 'high grade' solvent and 'cleaned high grade' solvent revealed that 12 of 15 target compounds were 100% BDL (Appendix 34). The three remaining target compounds (i.e., chloroform, benzene and napthalene) were respectively 14%, 62% and 76% BDL. The removal efficiency of the solvent cleaning procedure (Fellin, 1998) was determined to be 59% for chloroform, 86% for benzene and 49% for napthalene (Appendix 34). These results seem to suggest that most background contamination can be attributed to the PSD with the exception of chloroform, benzene and napthalene contamination for which the solvent appears to be partially responsible.

The accurate and precise measurement of solvent was ensured through use of a Hamilton® syringe and a Sigma® micropipette. The Hamilton® syringe used in the fall was calibrated using gravimetric analysis and observed to have an accuracy of ±0.1% and a precision (RSD) of ±0.2%. The use of the Hamilton® syringe was discontinued after the fall samples as it was found to be cumbersome. The Sigma® micropipette used in the winter was also calibrated and observed to have an accuracy of ±1.1% and a precision (RSD) of ±0.4%. These two instruments both provided high accuracy and good repeatability.

It is recommended by 3M (1998a) that the user "verify the recovery coefficients, since laboratory and analysis techniques can affect recovery coefficients." The investigators attempted to determine desorption efficiencies with results of these tests presented in Appendix 35. Percent recovery for all compounds, with the exception of napthalene, was well above 100% with mean recoveries ranging from 130% to 290%. The precision (RSD) determined from the standard deviation between the different spiked

volumes ranged from ±3% to ±40% and on average was ±26%. These results would suggest an error in procedures used to determine recoveries as the calculated values appeared to be roughly two times 3M's published values (3M, 1998a). The investigators reexamined the methods, data and associated calculations and could not discover the source of error. It is highly improbable that one could extract a much greater quantity of a compound than the PSD was exposed to. It was decided that it would be best to use recovery coefficients published by 3M (1998a) to perform the necessary calculations.

7.5.3 Laboratory Analysis Quality Assurance and Quality Control

Quality assurance and quality control protocols used in laboratory analysis discussed in section 6.0 required a methodology that maximized sensitivity, calibrated the instrument, tested control samples, performed duplicate samples, and followed laboratory procedures (Rose, 1999). Sensitivity is essentially determined by one's ability to differentiate a chemical signal from instrument noise. Samples with a signal to noise ratio of less than 4:1 were reported as BDL and those with a signal to noise ratio of greater than 4:1 were identified both qualitatively and quantitatively. As the signal to noise ratio varied from sample to sample, the sensitivity reported in Appendix 36 is mean method detection limits (MDL) and limits of quantification (LOQ) of seven randomly selected samples (Rose, 1999).

The MDL is the lowest concentration of a compound that can be qualitatively identified by a given procedure with a 99% level of confidence (EPA, 1994; Froese, 1999). The MDL ranged from 0.1 to 1.3 $\mu g/m^3$ with a mean of 0.3 $\mu g/m^3$ for the target compounds. This is higher sensitivity than that achieved in the national Canadian study which reported detection limits ranging from 0.4 to 6.3 $\mu g/m^3$ with a mean of 2.6 $\mu g/m^3$ (Otson and Meek, 1995). The LOQ is the lowest concentration of a compound that can be quantitatively identified by a given procedure with a 99% level of confidence (Froese, 1999). The LOQ ranged from 0.3 to 4.2 $\mu g/m^3$ with a mean of 1.2 $\mu g/m^3$ for the target compounds.

The methodology appeared to have sufficient sensitivity for most of the target compounds when sampling indoors. Median indoor VOC levels (Table 17) of

trichloroethylene, chlorobenzene and 1,4-dichlorobenzene did not exceed their MDLs resulting in one's being less certain of the presence of these compounds in indoor air. Median indoor VOC levels of carbon tetrachloride, benzene, tetrachloroethylene, napthalene and styrene exceeded their MDLs but not their LOQs resulting in one's being less certain of the quantity of these compounds in indoor air.

The methodology did not appear to have sufficient sensitivity for most of the target compounds when sampling outdoors. The median outdoor VOC levels exceeded the MDL only for 1,1,1-trichloroethane, carbon tetrachloride, toluene, ethylbenzene, xylenes, and 1,3,5-trimethylbenzene, and the LOQ was only exceeded by o-xylene. Thus, one may be certain of the presence of the aforementioned compounds in outdoor air but should place less confidence in the quantities of outdoor VOC levels with the exception of o-xylene.

The analytical method's accuracy was ensured through calibration and the performance of routine control samples (Rose, 1999). The accuracy of the instrument was variable but it was ensured that it was at least ±20% throughout the study by running a control sample after every tenth sample (Rose, 1999). Although, the limits of linearity were not determined, all of the samples were observed to be within the linear range of the calibration curves. The calibration curve for 1,1,1-trichloroethane (Appendix 37) demonstrates the target accuracy of ±20% and linearity (Rose, 1999). This is more accurate than the analytical accuracy reported for the TEAM studies of ±35% (Wallace, 1986a)

The analytical method's precision was determined by calculating the relative percent difference (RPD) between the duplicate samples (X1 and X2) (EPA, 1994):

$$RPD = \frac{100 \times (X1 - X2)}{\left[\frac{(X1 + X2)}{2}\right]}$$ **Equation 10**

The maximum analytical precision ranged from ±<1% to ±200% and the median level of precision ranged from ±<1% to ±68% for the target compounds (Appendix 38). The precision appears to be comparable to the median level of analytical precision reported

for the TEAM studies of 20 to 40% (Wallace, 1986a), with only four target compounds (i.e., benzene, ethylbenzene, napthalene and toluene) having analytical precision of greater than ±40%.

8.0 CONCLUSIONS

The purpose of this research was to evaluate the impact of industrial activity within the Strathcona Industrial Corridor upon residential air quality in Sherwood Park. This research was conducted in the fall and winter seasons and measured the concentrations of a limited number of target VOCs. There were three research objectives established to assist in directing this research towards its purpose. The first objective was to determine indoor and outdoor residential VOC levels in Sherwood Park and St. Albert. The results presented in Tables 6 to 20 allow indoor to outdoor, community, seasonal and international comparisons of residential levels of the target VOCs. Paired t-tests confirmed that there was a significant difference ($\alpha = 0.05$) between indoor and outdoor VOC levels justifying subsequent independent analysis of these two data sets. Paired t-tests also revealed no significant difference ($\alpha = 0.05$) between fall and winter VOC levels for most of target compounds justifying these two data sets being pooled for subsequent analysis.

The first part of the second objective was to determine whether a significant difference in indoor VOC levels exists between Sherwood Park and St. Albert. The t-tests conducted on this data observed no significant difference ($\alpha = 0.05$) for target compounds between indoor VOC levels in Sherwood Park and St. Albert. Further, an international comparison of indoor VOC levels (Table 20) demonstrated that these results appear to be comparable to those observed in the United States of America, Germany and the Netherlands. Thus, one must reject the study hypothesis stating that the close proximity of Sherwood Park to the Strathcona Industrial Corridor significantly increases indoor VOC levels.

The second part of the second objective was to determine whether a significant difference in outdoor VOC levels exists between Sherwood Park and St. Albert. These t-tests observed no significant difference ($\alpha = 0.05$) between outdoor VOC levels for most target compounds, but outdoor levels of benzene, toluene, ethylbenzene, xylenes and 1,3,5-trimethylbenzene were significantly higher in St. Albert. The community median concentration ratios revealed that St. Albert's outdoor VOC levels for benzene were 1.3

times higher, for ethylbenzene, xylenes and 1,3,5-trimethylbenzene were 2 times higher, and for toluene were 15 times higher than Sherwood Park's outdoor VOC levels.

The last objective was to determine residential indoor to outdoor VOC concentration ratios. The target compounds exhibiting significant indoor to outdoor differences, with the exception of toluene in Sherwood Park, were observed to have indoor VOC levels of 2 to 11 times outdoor VOC levels. The higher concentration ratios in Sherwood Park for toluene, ethylbenzene, xylenes and 1,3,5-trimethylbenzene were not likely the result of higher indoor concentrations of these compounds in Sherwood Park but rather the result of higher outdoor levels of these compounds in St. Albert.

9.0 FUTURE RESEARCH RECOMMENDATIONS

There are many avenues of research that may be pursued by community-based studies of this nature. This section provides a brief description of some possible areas for future research:

1. An investigation of residential VOC levels in other urban and rural areas (i.e., Edmonton, Leduc, Strathcona County, Leduc County) within Capital Health Region could be conducted. This would allow one to test the hypothesis that this study's results are likely also representative of other urban centres within Capital Health Region.
2. An investigation of outdoor VOC levels (i.e., benzene, toluene, ethylbenzene, xylene and 1,3,5-trimethylbenzene) in St. Albert using air pollution modeling could be conducted. This would allow one to obtain data towards explaining the reason these outdoor VOCs were significantly higher in St. Albert.
3. An investigation of residential VOC levels in relation to common sources of these compounds could be conducted. This could involve a similar study but where preliminary screening with a questionnaire allowed one to stratify the sample by source (e.g., smoker/nonsmoker, attached/detached garage, new/old house). This would also assist in removing additional confounders when comparing geographical areas.
4. A multitude of indoor air pollutants (e.g., bacteria, fungus, particulate matter, and other VOCs) in different microenvironments (e.g., residential, institutional, recreational and schools) could be investigated within a geographical region. This would allow one to accumulate baseline data for an area that could be used in conducting exposure assessments and towards improving indoor air quality.

10.0 REFERENCES

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11.0 APPENDICES

Appendix 1: HREB Request for Ethics Review.

**NOTE: This form has been designed to be used by researchers in a wide variety of fields. Some questions may not be pertinent for this particular project. It is extremely important to read the information and follow the instructions found in the Guidelines for Researchers. Please refer to the guidelines for all the submission information.

Section A:
General information.

A1. Title of Project: Community Air Sampling of Volatile Organic Compounds (VOC) in the Capital Health Region.

A2 Name of Principal Investigator: Warren Kindzierski
Title(s): Assistant Professor
Department / Program: Environmental Engineering
University of Alberta

Mailing address for ethics information: Steven Probert (492-8548)
Environmental Engineering
#304, Home Economics Building
University of Alberta
Edmonton, Alberta
T6G-2G7

Telephone: 492-0247 Fax: 492-8289 E-Mail: warren.kindzierski@ualberta.ca

Signature: _____ Date: _____

Name of Field Investigator 1: Steven Probert

Title(s): Environmental Health Officer and Graduate Student

Department / Program: Environmental Health, Capital Health and Civil & Environmental Engineering, University of Alberta

Telephone: 492-8548 Fax: 492-8289 E-Mail: sprobert@gpu.srv.ualberta.ca

Signature: _____ Date: _____

Name of Field Investigator 2: Christine Byrne-Lewis
Title(s): Graduate Student
Department / Program: Civil and Environmental Engineering
University of Alberta

Telephone: 492-8548 Fax: 492-8289 E-Mail: chrbyrne@gpu.srv.ualberta.ca

Signature: _____ Date: _____

A3. Name of Co-Investigator 1: (Required for Students, Residents, Visiting Scholars, etc.)

Name: Kenneth Froese
Title(s): Assistant Professor
Department/Program: Public Health Sciences
University of Alberta

Mailing address: Department of Public Health Sciences
13-103, Clinical Sciences Building
University of Alberta
Edmonton, Alberta
T6G-2G3

Telephone: 492-1190 Fax: 492-0364 E-Mail: kenneth.froese@ualberta.ca

Signature: _____ Date: _____

Name of Co-Investigator 2: (Required for Students, Residents, Visiting Scholars)

Name: Daniel Smith
Title(s): Professor
Department/Program: Environmental Engineering
University of Alberta

Telephone: 492-4138 Fax: 492-8289 E-Mail: dwsmith@civil.ualberta.ca

Signature: _____ Date: _____

A4. Authorizing Signatures:

I support the implementation of this project.

_____ _____
Dr. Terry Hrudey, Chair Date
Civil and Environmental Engineering
University of Alberta

A5. Thesis Committee:

Name	Department / Program	Telephone
1. Warren Kindzierski	Environmental Engineering	492-0247
2. Kenneth Froese	Public Health Sciences	492-1190
3. Daniel Smith	Environmental Engineering	492-4138

A6. Expedited review:

This research has already received tentative approval for an expedited review. This approval was received in correspondence from Karen Turpin, who apparently discussed the matter with Dr. Sharon Warren. The original rationale for an expedited review consisted of the following points:

- no invasive procedures on participants
- no health records needed
- no health status data collected
- only samples taken are indoor and outdoor air samples
- questionnaire will extract the following types of information:
    - basic characteristics of the house
    - basic information on the household habitants including: name, occupation/student, and smoking status
    - what the potential VOC sources are in the house
    - what recent household activities may be potential VOC sources

A7. Which one of the following best describes the type of investigation proposed? Check more than one if appropriate.

This is a pilot study collecting information on potential confounders to the study through field questionnaires, and collecting air quality data through a direct method of field sampling and subsequent laboratory analysis.

A8. Where will the research be conducted? (Note that administrative approval is required to carry out research in any Capital Health or Caritas facility):

- air samples collected at residences within the communities of Sherwood Park and St. Albert in Alberta
- questionnaires completed at the same residences
- samples analysed by the Department of Public Health Sciences, University of Alberta

Funding/Budget

A9. How is the proposal funded?

✓ funding approved (specify source): Department of Civil & Env. Engineering
University of Alberta and
Community Care and Public Health
Capital Health Authority

___ funding request pending (specify source):

___ no external funding required

A10. Are any of the investigators involved in this study receiving any direct personal remuneration or other personal or family financial benefits (either direct or indirect) for taking part in this investigations? (See guidelines, page 7)

___ yes If yes, append a letter detailing these activities to the Chair of the appropriate review committee.

✓ no

Attach a budget summary. You may contact Warren Kindzierski if this information is required.

Additional Documentation

A11. If any of the following applies to this study, attach the appropriate letters of approval / support. (See Guidelines page 8)

Health Protection Branch or other Canadian federal agency approval:
✓ Not applicable
___ Attached
___ Pending

Radiation Safety Committee Approval (required for all studies involving radioisotopes and non-routine X-rays):
✓ Not applicable
___ Attached
___ Pending

Electromechanical or Biohazardous Materials Safety Approval:
✓ Not applicable
___ Attached
___ Pending

Section B:
Details of Project
{Note that spaces have been minimized in this electronic version of the form. Use cut and paste to add information. Do **NOT** indicate that the board should see attached.}

Description of the Project

B1. Provide a clear statement of purpose and objectives of the project.

The **purpose** of this study is to evaluate the impact of industrial emissions from the Strathcona industrial corridor upon the residential air quality of the nearby community of Sherwood Park.

The **objectives** of this research are:

- to assess the impact of proximity to industry upon a residential community's air quality
- to determine the concentration of specific VOCs in the residential communities of Sherwood Park and St. Albert within the Capital Health Region
- to compare the air quality of Sherwood Park to that of St. Albert

B2. State **hypotheses** and / or research questions.

The hypotheses to be tested is that the close proximity of Sherwood Park to industrial emissions does not significantly increase the indoor air concentration of specific VOCs (attachment 10), and subsequently the contribution of industrial emissions to the exposure of residents of these communities to VOCs is relatively small.

B3. Briefly summarize **past human and/or animal research** which has led to this project. (1 page maximum, 12 point font)

- total human exposure studies demonstrating the importance of a receptor oriented approach for exposure assessment
- human time activity studies demonstrating the importance of indoor air quality (IAQ) to exposure
- research demonstrating adverse health effects of VOCs:
  1. suspected or proven human carcinogens including benzene, chloroform, trichloroethylene, trichloroethane, and formaldehyde.
  2. eye, skin, and respiratory irritation with possibly severe reactions in susceptible subpopulations (eg. Reactive Airway Dysfunction Syndrome).
  3. believed to exacerbate asthmatic symptoms.
  4. may induce Chronic Obstructive Pulmonary Disease (COPD)
  5. responsible for odors whose main effect is upon a person's mental health and productivity.
- Total Exposure Assessment Methodology (TEAM) studies demonstrating:
  - the importance of IAQ to exposure to VOCs
  - the importance of air as the primary medium of exposure to VOCs
  - the importance of indoor air relative to outdoor air exposure
  - the importance of indoor VOC sources relative to air exchange rates
  - the importance of personal activities to increased VOC exposure
- International IAQ studies demonstrating:
  - the seasonal variations in VOC concentrations
  - the potential sources of VOC emissions
  - the importance of IAQ to exposure to VOCs
  - the importance of air as the primary medium of exposure to VOCs
  - the types of VOCs present in indoor and outdoor air

Description of Sample/Population.

B4. Describe the numbers and type(s) of subjects to be included. If appropriate, specify number of subjects in each study group. Provide a rationale for the sample size and include sample size calculations where appropriate.

There will be approximately 30 dwelling units participating from each community.

The number of dwelling units are limited by the study's budget. The selection of 30 samples from each community allows one to assume that the results of the VOC tests for each community are normally distributed, and to apply parametric tests when comparing the two communities.

B5. List any inclusion/exclusion criteria.

Some multi-family dwellings, institutions and trailer homes will be excluded from the study as they introduce another confounder into the study. The sample will include single family dwellings, but this is still being defined.

B6. Will participants be recruited who are:

Under 18 years of age	[ ] yes [✓] no
Cognitively impaired	[ ] yes [✓] no
Residing in institutions (e.g. prison, extended care facility)	[ ] yes [✓] no
Students	[✓] yes(*)[ ] no
Employees of researcher(s)' organization	[✓] yes(*)[ ] no
In emergency or life-threatening situations	[ ] yes [✓] no
Have language barriers (eg. illiterate, not English-speaking, dysphasic)	[ ] yes [✓] no
In another country	[ ] yes [✓] no

* The homes of students and employees will be included if they are randomly selected as part of the sample.

The participants will have to have the authority to give us permission to place the samplers in the housing premises. This means that our participants will be either the homeowners or the tenants of the housing premises. Further, the investigators must be able to communicate with the participants at a level which allows them to explain the study, obtain consent, and complete the questionnaire.

Description of Research Procedures

A. House Selection:

- houses will be sampled from the communities of Sherwood Park which is in close proximity and downwind of industrial emissions, and the control community of St. Albert which is not in close proximity and upwind of industrial emissions
- stratified sampling approach ensuring a good geographical distribution of the samples taken within the two communities:
  - First Stage Sampling: proximity strata in relation to industrial emissions established for each community.
  - Second Stage Sampling: geographical area strata established within proximity strata to ensure good geographical distribution and to improve operational feasibility.
  - Third Stage Sampling: cluster sample with random selection of starting home within each of the geographical areas.

B. Field Procedures:

- distribute promotional recruitment pamphlet (Pre-Visit)

- **Door to Door Campaign** for participants (Visit 1):
  - introduce ourselves and ask if the owner of the house is home
  - hand-out the *Introductory Letter* (attachment 3) and *Information Sheet* (attachment 4)
  - briefly explain the study in reference to the *Introductory Letter* and *Information Sheet*. The commitment required by the participant will be explained at this point.
  - ask the participant if they would like to participate:
    - if no, than complete the *Refusal Form* (attachment 5), thank them for their time and proceed to the next house
    - if yes, than the *Consent Form* (attachment 6) is reviewed and completed and this process continues
  - *Questionnaire: Household Characteristics* (attachment 7) is reviewed and left for the participant to complete (explain heating system table)
  - schedule Visit 2 and 3

- **Stage 1 (Fall) Data Collection (Visit 2):**
  - arrive at pre-scheduled time
  - inquire about *Questionnaire: Household Characteristics* and answer any questions
  - deploy samplers inside and outside as per *Sampling Protocol* (attachment 8)
  - complete *Chain of Custody* form (attachment 9)
  - reminder of Visit 3 within 24 hours

- **Stage 1 Data Collection (Visit 3):**
  - arrive at pre-scheduled time
  - inquire about and pick-up the *Questionnaire: Household Characteristics*
  - pick-up samplers as per *Sampling Protocol*
  - complete *Chain of Custody* form
  - interview to complete *Questionnaire: Household Activities*
  - thank the participant for their time and remind them of the Stage 2 (Winter) Data Collection
  - transport samples to lab for storage in refrigerator

- **Stage 2 (Winter) Data Collection (Visit 4):**
  - Participant Reminder and Scheduling
    - distribution of reminder letter (Pre-Visit)
    - door to door campaign:
      - reintroduce ourselves and provide study update
      - confirm continued participation
      - *Questionnaire : Household Changes* reviewed and left for the participant to complete
      - schedule Visit 5 and 6
- **Stage 2 Data Collection (Visit 5):**
    - arrive at pre-scheduled time
    - inquire about *Questionnaire : Household Changes* and answer any questions
    - deploy samplers inside and outside as per *Sampling Protocol*
    - complete *Chain of Custody* form
    - reminder of Visit 6 within 24 hours
- **Stage 2 (Winter) Data Collection (Visit 6):**
  - arrival at pre-scheduled time
  - pick-up *Questionnaire : Household Changes*
  - pick-up both samplers
  - complete *Chain of Custody* form
  - interview to complete *Questionnaire: Household Activities*
  - thank the participants for their cooperation

C. Air Sampling and Analysis Equipment:

- air sampler:
  - 3M's OVM 3500
  - passive sampler
  - activated carbon badge
- lab analysis:
  - carbon disulphide extraction
  - gas chromatography-mass spectroscopy analysis for targeted VOCs

D. Questionnaire:

- purpose of the questionnaire:
  - to determine confounding factors in an attempt to later explain any anomalous data
- *Questionnaire: House Characteristics*
  - will be given to the participant during Visit 1
  - self-administered and to be completed for pick-up during Visit 3
  - data collection on basic house characteristics which may confound results
- *Questionnaire: Household Activities*
  - completed by researchers interviewing the participant during Visit 3
  - data collection on the household habitants (ie. name, occupation/student, smoker)
  - data collection on potential VOC sources in house
  - data collection on recent household activities as potential VOC sources
- *Questionnaire: Changes to House Characteristics*
  - will be given to the participant during Visit 4
  - self-administered and to be completed for pick-up during Visit 6
  - data collection on basic house characteristics which may confound results
  - determine if there have been any changes to house characteristics since the fall
- *Questionnaire: Household Activities*
  - completed by researchers interviewing the participant during Visit 6
  - data collection on the household habitants (ie. name, occupation/student, smoker)
  - data collection on potential VOC sources in house
  - data collection on recent household activities as potential VOC sources

Obtaining Consent

B10. Clearly detail who will be recruiting subjects and obtaining consent, and the procedures for doing this. If appropriate, specify whether subjects will be randomly assigned to groups before or after consent has been attained.

The field investigators will be recruiting the participants and obtaining consent, as described above. All participants, in both communities, will be treated the same.

B11. Attach a copy of consent form(s), information sheets and all recruitment notices, letters or advertisements. (See Appendix A of Guidelines. Use of standard Consent is highly recommended.)

Attachments:
Recruitment Pamphlet
Information Letter
Information Sheet
Recruit Refusal Form
Recruit Consent Form

B12. Specify methods for dealing with groups identified in #B6. If the subjects are not able/competent to give fully informed consent, who will consent on their behalf?

The excluded dwellings will not be approached, and if we approach an individual who is not capable of participating then we will thank them for their time and politely exclude them from the study.

B13. What is the reading level of the Information Letter?
What is the reading level of the Consent Form?
(For most populations, the target level is Grade 8. See Appendix A of Guidelines for information on calculating reading level. The Standard Consent Template is Grade 7.)
What steps have been taken to make the consent form and subject information documents comprehensible to the person giving consent? (Please include a statement on how the reading level was determined, i.e.: level was determined using Word Perfect 6.0)

Document	Flesch-Kincaid Grade Level (*)
Recruitment Pamphlet	8.5
Information Letter	8.4
Information Sheet	8.7
Participant Consent Form	8

*These grade levels were determined using Word 7.0 Grammar check.
All of the documents were reviewed by the investigators, Capital Health's review team, and peers. They were also pre-tested during our trial runs from August 10 to 13, 1998.

B14. If subjects will be offered compensation for participating in the research, provide details. Specify the amount, what the compensation is for, and how payment will be determined for subjects who do not complete the study.

No compensation.

B15. Do any of the procedures include the use of deception or partial disclosure of information to subjects?

[ ] yes — Provide rationale for deception or partial disclosure. Describe the procedures for (a) debriefing the subjects and (b) giving them a second opportunity to consent to participate after debriefing.

[✓] no

Risks and Benefits

B16. What are the benefits of the proposed research for the subject and / or for scientific knowledge in general?

There are no direct benefits to the participants. The results of the air sampling done in their home and the research reports will be available to them. However, the field investigators will not include an interpretation of the results for an individual's home. If a participant expresses concern about the air quality results, they will be asked to direct their concerns to Alberta Environment if they're concerned about the ambient air quality, or to Capital Health if they are concerned about their indoor air quality.
The benefits to the scientific community are the objectives of the study.

B17. What adverse effects may result from the research? (Include risks, discomfort, incapacity, psychological risks, and any reported side-effects of procedure or drug.) How will adverse effects be dealt with?

There are no anticipated health or safety risks to the participants or their home.

Privacy and Confidentiality

B18. What steps will be taken to respect privacy of subjects and protect confidential data?

This study will not include any reference to personal information within the research paper, and at no point will any personal information be released to anyone that is not affiliated with this research.

B19. Identify any agencies or individuals who will have access to confidential data now or in the future.

Individuals:	Investigators, thesis committee, and research assistants.
Agencies:	Capital Health Authority and the University of Alberta

B20. Do you anticipate secondary analysis of these data? (Note that secondary analysis requires further research ethics approval.)

___ Yes
✓ No

Attachments:

1. ***Proposal for Community Air Sampling of VOCs in Capital Health Region; Warren Kindzierski; 1998***
2. ***Recruitment Pamphlet***
3. ***Information Letter***
4. ***Information Sheet***
5. ***Recruit Refusal Form***
6. ***Recruit Consent Form***
7. ***Questionnaire***
8. ***Sampling Protocol***
9. ***Chain of Custody***
10. ***Targeted VOCs***

Appendix 2: HREB Health Research Ethics Approval.

University of Alberta
Edmonton
Canada T6G 2G4

Faculty of Rehabilitation Medicine
Rehabilitation Research Centre
3-48 Corbett Hall
Director (403) 492-7856 Telephone (403) 492-2903
Fax (403) 492-1626

September 22, 1998

Dr. Warren Kindzierski
c/o Steven Probert
304 Home Economics Building
Department of Environmental Engineering

Dear Dr. Kindzierski,

Re: Community Air Sampling of Volatile Organic Compounds (VOC) in the Capital Health Region.

Please find enclosed your letter of ethical approval for the above project. On behalf of the Health Research Ethics Board (B: Health Research), I wish you every success in your research endeavours.

Sincerely,

Karen Turpin

Karen Turpin, RN, BScN
Administrative Assistant
Health Research Ethics Board (B: Health Research)

University of Alberta
Edmonton
Canada T6G 2G4

Faculty of Rehabilitation Medicine
Rehabilitation Research Centre
3-48 Corbett Hall
Director (403) 492-7856 Telephone (403) 492-2903
Fax (403) 492-1626

UNIVERSITY OF ALBERTA HEALTH SCIENCES FACULTIES, CAPITAL HEALTH AUTHORITY, AND CARITAS HEALTH GROUP

HEALTH RESEARCH ETHICS APPROVAL

Date: September 1998

Name(s) of Principal Investigator(s): Dr. Warren Kindzierski

Organization(s): University of Alberta

Department: Department of Civil and Environmental Engineering

Project Title: Community Air Sampling of Volatile Organic Compounds (VOC) in the Capital Health Region.

The Health Research Ethics Board has reviewed the protocol for this project and found it to be acceptable within the limitations of human experimentation. The HREB has also reviewed and approved the patient information material and consent form.

The approval for the study as presented is valid for one year. It may be extended following completion of the yearly report form. Any proposed changes to the study must be submitted to the Health Research Ethics Board for approval.

Sharon Warren

Dr. Sharon Warren
Chair of the Health Research Ethics Board (B: Health Research)

File number: B-070998-ENG

Notice to All Researchers

In carrying out this project, remember it is your responsibility to:

1) Submit any changes to the protocol / proposal for HREB approval.

2) Keep signed copies of the consent form and all raw data (i.e.: tape transcriptions) for at least 7 years following the completion of the study.

3) Ensure that the process of obtaining informed consent is carried out in a way that provides complete information to potential research participants and avoids coercion.

4) Monitor the safety of research procedures and equipment. The HREB must be notified about any adverse events.

5) Preserve the confidentiality of research subjects and store records in a secure area.

6) Ensure that information collected and analysed is complete and accurate.

Appendix 3: Notice of Administrative Approval for Proposed Research.

Capital Health

Regional Research Administration Office
CSB 9-122, 492-1372

NOTICE OF ADMINISTRATIVE APPROVAL FOR PROPOSED RESEARCH

Site: CHA Communities

Project Title:	Community Air Sampling of Volatile Organic Compounds (VOC) in the Capital Health Region
Project Number:	K-051
Investigator Name:	Kindzierski, W. Dr.
Department:	Civil and Environmental Engineering
Division:	Environmental Engineering
Address:	#304, Home Economics Building
Phone:	(403) 492-0247 **Fax:** (403) 492-8289

Supporting Documents:

Ethics Appoval Date:	04-Sep-98
Ethics File #:	B-070998-ENG
Study Protocol	Received with Ethics Package
Source of Funds:	NSERC Research Grant, County of Strathcona, City of St. Albert, Friends of the Environment
Type of Funds:	Grants
Overhead rate:	0
Account Number:	U of A 52-75156 & 52-25042
Contract Finalized Date:	
Revised:	

Project Approved: 14-Oct-98

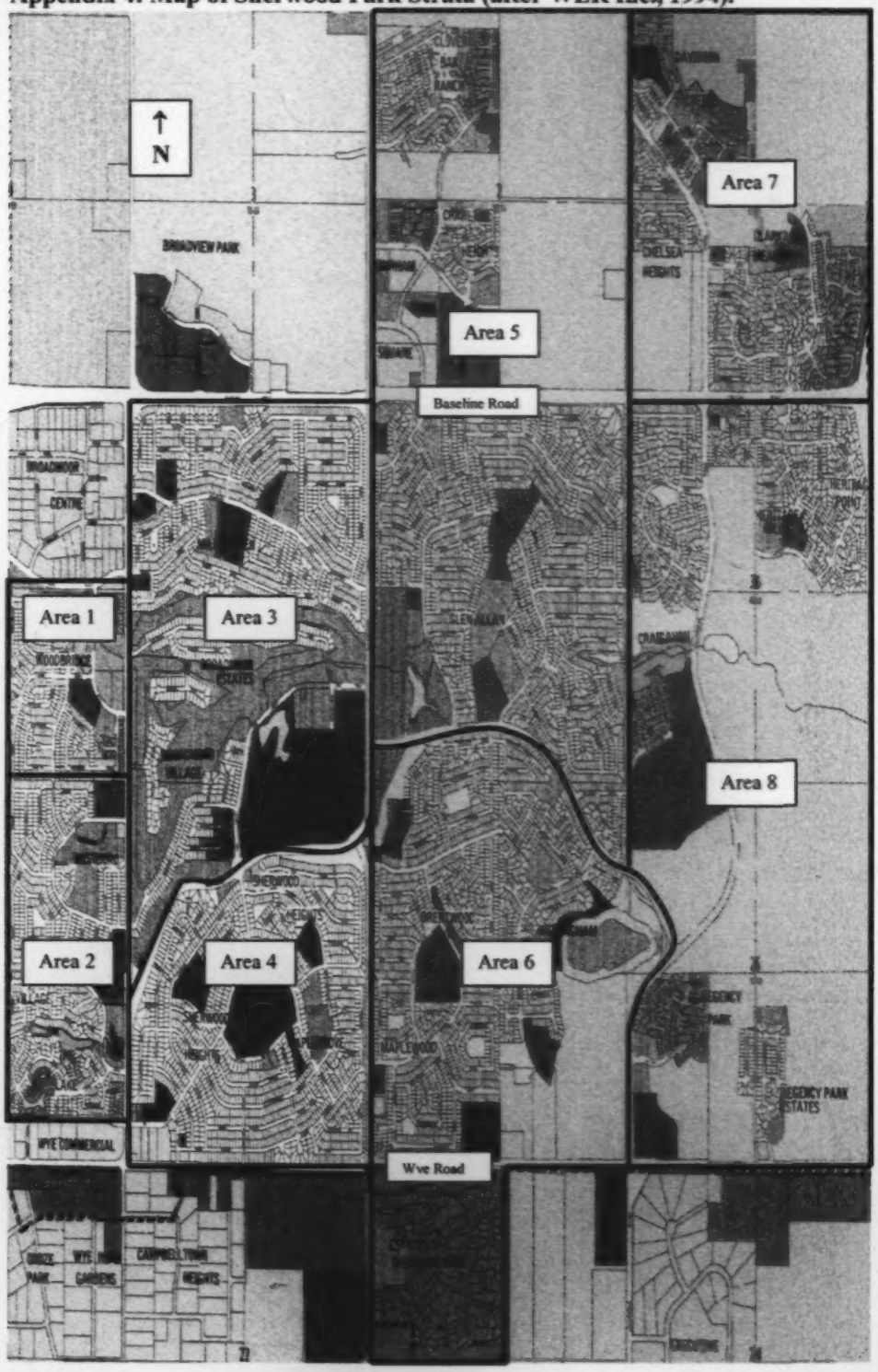
THIS APPROVAL IS VALID FOR ONE YEAR

Valerie Elias, Manager
Regional research Administration

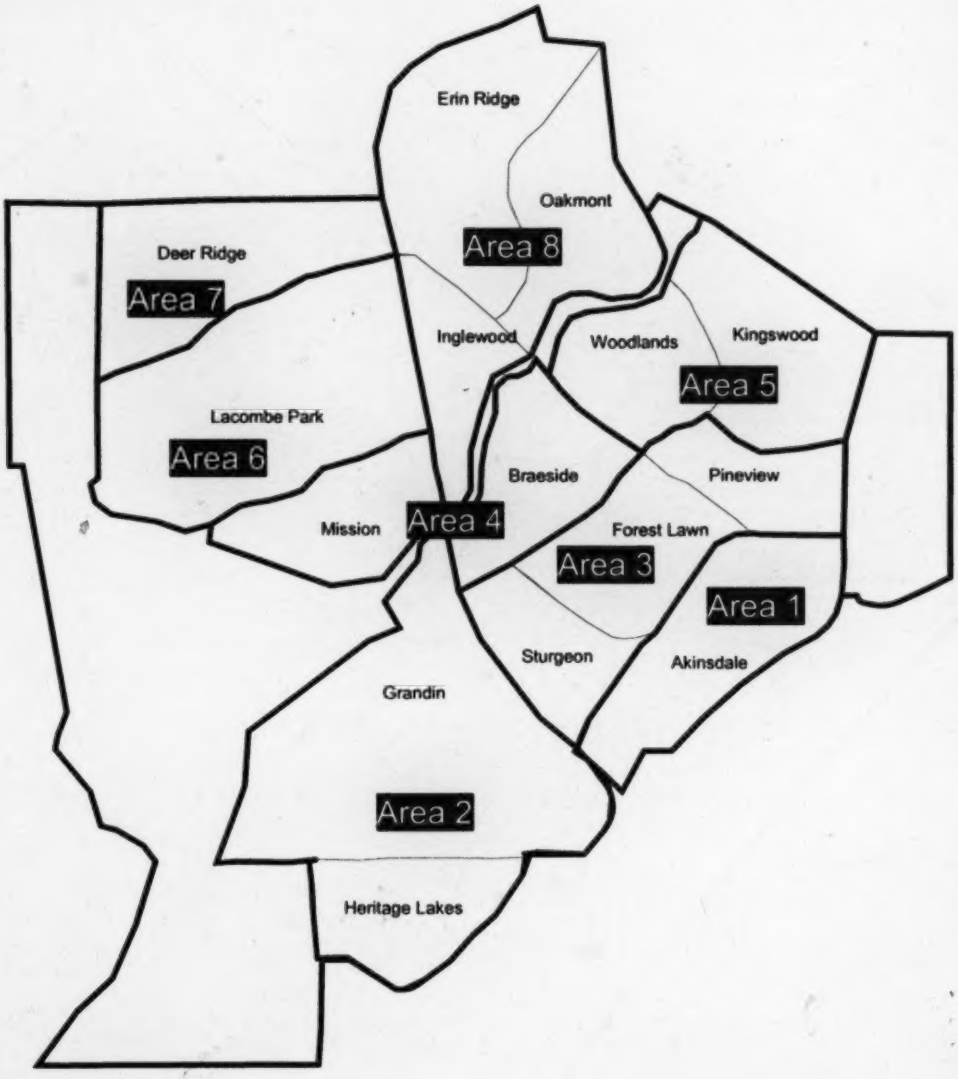
Valerie Elias

Copies to: Department Chair/Health Sciences Faculty
Vicky Afacan, Director, Accounting Services
Phil Heuchert, Manager Trust Research Accounts

Appendix 4: Map of Sherwood Park Strata (after WER Inc., 1994).



Appendix 5: Map of St. Albert Strata.



Appendix 6: Sampling Distribution Estimates and Results.

Appendix 6a: Sherwood Park Sampling Distribution Estimate:

Community Name	Dwelling Units (DU)	DU (% Total)	Dwellings (% IEP)	Samples per Strata (n)	Samples per Subarea by IEP	Samples Proposed
Industrial Emissions Proximity 1:						
Area 1:						
Woodbridge	989					
Subtotal	989	7.9%	42.0%		3.4	3
Area 2:						
Westboro	767					
Village on the Lake	600					
Subtotal	1367	10.9%	58.0%		4.6	5
IEP Total	2356	18.8%	100.0%	8.0		8
Industrial Emissions Proximity 2:						
Area 3:						
Broadmoor Estates	200					
Broadmoor Village	517					
Mills Haven	1211					
Subtotal	1928	15.4%	56.2%		4.5	4
Area 4:						
Sh Hts/Maple Grove	1503					
Subtotal	1503	12.0%	43.8%		3.5	4
IEP Total	3431	27.4%	100.0%	8.0		8
Industrial Emissions Proximity 3:						
Area 5:						
Charlton Heights	214					
Cloverbar Ranch	351					
Glen Allan	1965					
Subtotal	2530	20.2%	57.2%		4.6	5
Area 6:						
Brentwood/Maplewood	1342					
Est. of Sh. Park	146					
Nottingham	407					
Subtotal	1895	15.1%	42.8%		3.4	3
IEP Total	4425	35.4%	100.0%	8.0		8
Industrial Emissions Proximity 4:						
Area 7:						
Chelsea Heights	102					
Clarkdale Meadows	574					
Davidson Creek	362					
Lakeland Village						
Subtotal	1038	8.3%	45.0%		3.6	4
Area 8:						
Craigavon	477					
Heritage Hills/Pt/Cr	457					
Regency Pk	260					
The Ridge	73					
Subtotal	1267	10.1%	55.0%		4.4	4
IEP Total	2305	18.4%	100.0%	8.0		8
Grand Total	12517	100.0%		32.0		32

Appendix 6b: St. Albert Sampling Distribution Estimate.

Community Name	Dwelling Units (DU)	DU (%)	Samples per Subarea by DU	Dwellings (% IEP)	Samples per Strata	Samples per Subarea by IEP	Samples Proposed
Industrial Emissions Proximity 1:							
Area 1:							
Akinsdale	1639						
Subtotal	1639	11.0%	3.3	21.6%		2.2	2
Area 2:							
Grandin	3111						
Heritage Lakes	498						
Subtotal	3609	24.1%	7.2	47.5%		4.8	5
Area 3:							
Sturgeon	693						
Forest Lawn	1037						
Pineview	619						
Subtotal	2349	15.7%	4.7	30.9%		3.1	3
IEP Total	7597	50.8%	15.2		10.0		10
Industrial Emissions Proximity 2:							
Area 4:							
Braeside	1025						
Mission	689						
Downtown	0						
Subtotal	1714	11.5%	3.4	60.4%		6.0	6
Area 5:							
Woodlands	932						
Kingswood	192						
Subtotal	1124	7.5%	2.3	39.6%		4.0	4
IEP Total	2838	19.0%	5.7		10.0		10
Industrial Emissions Proximity 3:							
Area 6:							
Lacombe Park	2165						
Subtotal	2165	14.5%	4.3	47.8%		4.8	5
Area 7:							
Deer Ridge	1374						
Subtotal	1374	9.2%	2.8	30.4%		3.0	3
Area 8:							
Inglewood	395						
Erin Ridge	427						
Oakmont	165						
Subtotal	987	6.6%	2.0	0.2		2.2	2
IEP Total	4526	30.3%	9.1		10.0		10
Grand Total	14961	100%	30.0				30

Appendix 6c: St. Albert's Sampling Distribution Results.

Area	Community	ID	Address	Recruits
Proximity 1				
1	Akinsdale	Confidential	Confidential	2
2	Grandin	Confidential	Confidential	5
3	Forest Lawn	Confidential	Confidential	3
Sub Total				**10**
Proximity 2				
4	Braeside	Confidential	Confidential	6
5	Woodlands	Confidential	Confidential	4
Sub Total				**10**
Proximity 3				
6	Lacombe Park	Confidential	Confidential	5
7	Deer Ridge	Confidential	Confidential	3
8	Erin Ridge	Confidential	Confidential	2
Sub Total				**10**
Total				**30**

Appendix 6d: Sherwood Park's Sampling Distribution Results.

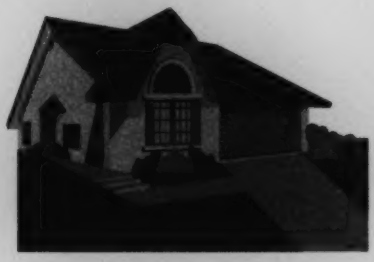
Area	Community	ID	Address	Recruits
Proximity 1				
1	Woodbridge	Confidential	Confidential	3
2	Westboro	Confidential	Confidential	5
Sub Total				**8**
Proximity 2				
3	Millshaven	Confidential	Confidential	4
4	Sherwood Heights	Confidential	Confidential	4
Sub Total				**8**
Proximity 3				
5	Durham Town Square	Confidential	Confidential	5
6	Brentwood	Confidential	Confidential	3
Sub Total				**8**
Proximity 4				
7	Clarkdale Meadows	Confidential	Confidential	4
8	Regency Park	Confidential	Confidential	4
Sub Total				**8**
Total				**32**

Appendix 7: Recruitment Pamphlet.

Community Air Sampling Program

UNIVERSITY OF ALBERTA

Capital Health



Two researchers from the University of Alberta will be in your area during the month of September. The researchers will be recruiting volunteers for an air quality study. About 35 volunteers are needed from your area. The objective of the study is to test if that being close to industry increases the levels of air pollutants in homes.

This study is a result of concerns raised by residents of Sherwood Park regarding the quality of the air in their community. Air pollutants will be monitored at the homes of volunteers in Sherwood Park and St. Albert.

Air sampling at your home will be done in the fall and winter over 24 hours. The monitors are small and noiseless. Volunteers will be needed for a few hours over two days in both the fall and winter. The time requirement considers drop-off and pick-up of samplers, plus the completion of a questionnaire.

Your participation is vital to the success of this research. With your help, valuable information on the quality of the air in Sherwood Park and St. Albert can be gained.

August 1998

For more information please contact:

Christine Byrne
University of Alberta

or

Steven Probert
Capital Health Authority

at 492-8548

Principal Investigator:
Dr. Warren Kindzierski
University of Alberta

Co-Investigators:
Dr. Ken Froese (U of A)
And
Dr. Daniel Smith (U of A)

Appendix 8: Field Recruitment Protocol.

Recruitment Attempt #1:

1. begin with the random starting dwelling within each strata,
2. proceed to the adjacent dwelling on the right when facing the last dwelling **Household Activities** from the front street,
3. if one can not proceed right than proceed to the dwelling across the street, and
4. repeat step 2 and 3 until either:
    - all of the participants needed in the strata consent to participate, or
    - all of the targeted houses for recruitment have been approached.

Recruitment Attempt #2:

1. return to the strata where there are more participants needed, and
2. return to the targeted houses within these strata which have given neither consent nor refusal.

Recruitment Attempt #3:

1. return to the strata where there are more participants needed,
2. return to the targeted houses within these strata which have given neither consent nor refusal,
3. proceed to step 4, beyond the targeted houses, if all the targeted houses have either:
    - consented to participate,
    - refused to participate, or
    - received three recruitment attempts.
4. proceed to the adjacent dwelling on the right when facing the last targeted dwelling from the front street,
5. if one can not proceed right than proceed to the dwelling across the street, and
6. repeat steps 4 and 5 until all of the participants needed have been obtained.

Appendix 9: Recruitment Campaign Field Procedure.

- visibly display picture ID on person
- introduce ourselves and ask if the owner or tenant of the house is home:
    - if he is unavailable than leave a *Sorry We Missed You* (Appendix #) flyer in the mailbox or with the person who is home
    - if he is available than try to recruit him as follows
- ask if he received the *Recruitment Pamphlet*
- briefly explain the purpose of the study and it's benefits
- ask if he would like to participate:
    - if no, than:
        - thank them for their time,
        - complete the *Recruitment Status* form, and
        - proceed to the next house
    - if yes, than:
        - hand-out the *Introductory Letter* and *Information Sheet*
        - explain the study in reference to the *Introductory Letter* and *Information Sheet* including:
            - commitment required by the participant
            - advise that they are not obligated to participate and are free to withdraw at anytime
            - advise participant that advice from Capital Health is available on improving indoor air quality
            - advise participant Capital Health will be informed immediately if unacceptable levels of an air toxic are revealed
            - advise participant that these data will be stored in a secure location by the University of Alberta for 7 years
        - the *Participant Consent Form* is reviewed and completed
        - *Questionnaire: Household Characteristics* is reviewed and left for the participant to complete prior to the scheduled sampling visits
            - explain heating system table
            - advise participant that they do not have to answer any questions they do not wish to
        - schedule Visits 2 and 3 for data collection
        - complete *Recruitment Status* form

Appendix 10: Introduction Letter.

September 1998

Dear Resident:

I am writing to tell you about a joint study we are doing with two graduate students from the University of Alberta. We want to measure concentrations of air pollutants inside and outside of homes in Sherwood Park and St. Albert. These data will be used to examine if industrial emissions affect the quality of the air in your community.

Attached is an information sheet that will answer some of the questions you may have about the study. Participation in the study is up to you. We would be pleased if you would participate. If you choose not to participate, services provided to you by the Capital Health Authority will not be affected.

Thank you very much.

Sincerely,

Dr. Gerry Predy
Medical Officer of Health
Capital Health Authority

Dr. Warren Kindzierski
Environmental Engineering
University of Alberta

Appendix 11: Information Sheet.

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators: Dr. Ken Froese
University of Alberta

Dr. Daniel Smith
University of Alberta

Field Investigators: Steven Probert
Capital Health Authority
492-8548 or 413-7927

Christine Byrne-Lewis
University of Alberta
492-8548

Purpose of Research:

Public concern exists about the effect of local industries upon air quality and health. Capital Health is working with the University of Alberta to look into this issue more closely.

Background Information:

The environment in which we live is important to our health. We receive exposure to pollution in our air, food, water, and soil. This study focuses on industrial pollution and its effect on local air quality.

The air pollutants being investigated are volatile organic compounds (VOC). Common sources include cars, industries, forest fires, cigarette smoking, building materials, and cleaning products.

Why did you approach me to participate?

There was a random selection of homes from within your community.

What if I do not want to participate?

You do not have to participate in this study. If you do not participate, it will not affect any of the services provided to you.

What is my role as a participant?

Your participation involves the completion of a questionnaire and allowing us to place air samplers at your home in the fall and winter seasons. All of the visits to your home will be made by the field investigators, Steven Probert and Christine Byrne-Lewis.

At our first visit, in September 1998, we explain the study and answer your questions. If you consent to participate, you will receive a short (~10 minutes) questionnaire to complete about the characteristics of your home.

At the second scheduled visit (~30 minutes), we place some small, silent air samplers inside and outside of your home.

At the third scheduled visit (~30 minutes), 24 hours later, we pick-up the samplers and questionnaire. We also briefly interview you about possible indoor VOC sources.

Your participation during January or February repeats the above process.

Are there any risks or benefits?

There are no known health and safety risks associated with this study.

The benefits include the results of your home's air quality. This information will be available upon request in April 1999. If you have any concerns about these results, please contact Capital Health at 413-7927.

The field investigators will report the results of the entire study in their graduate theses.

How will the information collected be kept confidential?

The records relating to this study are confidential. The investigators and Capital Health will have access to these records to develop research reports. Any report published as a result of this study will not identify you by name.

Whom can I call with questions?

If you have questions about this study you may contact Steven or Christine. If you have concerns about the nature of this study, you may also call the Patient Concerns Office of Capital Health (492-4845). This office has no direct affiliation with the investigators.

Appendix 12: Participant Consent Form.

Research Id #: _____

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators: Dr. Ken Froese
University of Alberta

Dr. Daniel Smith
University of Alberta

Field Investigators: Steven Probert
Capital Health Authority
492-8548 or 413-7927

Christine Byrne-Lewis
University of Alberta
492-8548

Please complete this short form:

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the Information Sheet?	Yes	No
Do you understand the benefits and that there are no known risks involved in taking part in this research study?	Yes	No
There may be additional analysis of these data at a later date, but it will not require any additional participation. Do you consent to this?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason.	Yes	No
Has the issue of confidentiality been explained to you?	Yes	No

This study was explained to me by:

- Steven Probert ☐
- Christine Byrne-Lewis ☐

I agree to take part in this study:

Signature of Participant	Date
Printed Name	Phone No.
Street Address	City/Hamlet

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate:

Signature of Investigator	Date

A COPY OF THE INFORMATION SHEET MUST BE GIVEN TO THE PARTICIPANT.

Appendix 13: Fall Monthly Scheduling Templates.

September 1998

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8 R	9 R	10 R	11 R	12
13	14 R	15 R	16 R	17 R	18 R	19
20	21 S 1	22 S 1	23 S 2	24 S 2	25 S 3	26 S 3
27	28 S 4	29 S 4	30 S 5			

October 1998

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1 S 5	2 S 6	3 S 6
4	5 S 7	6 S 7	7 S 8	8 S 8	9	10
11	12	13 S 9	14 S 9	15 S 10	16 S 10	17 S 11
18 S 11	19	20 S 12	21 S 12	22 S 13	23 S 13	24 S 14
25 S 14	26	27 S 15	28 S 15	29 S 16	30 S 16	31

Appendix 14: Winter Monthly Scheduling Templates.

January 1999

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1 New Year's	2
3	4	5 P	6 P	7 P	8 P	9 P
10 Christine	11 S 1	12 S 1	13 S 2	14 S 2	15 S 3	16 S 3
17 Steve	18 S 4	19 S 4	20 S 5	21 S 5	22 S 6	23 S 6
24 Christine	25 S 7	26 S 7	27 S 8	28 S 8	29 S 9	30 S 9
31						

February 1999

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Steve	1 S 10	2 S 10	3 S 11	4 S 11	5 S 12	6 S 12
7 Christine	8 S 13	9 S 13	10 S 14	11 S 14	12 S 15	13 S 15
14 Steve	15 Family Day	16 S 16	17 S 16	18 S 17	19 S 17	20

Appendix 15: Daily Scheduling Templates.

Appendix 15a: Fall Daily Scheduling Template.

Date:

		Community	Name	Address	Telephone
10:00 AM	Leave U of A				
10:30 AM 11:00 AM	do				
11:30 AM 12:00 PM	do				
12:30 PM 1:00 PM	do				
1:30 PM 2:00 PM	do				
2:30 PM 3:00 PM	do				
3:30 PM 4:00 PM	do				
4:30 PM 5:00 PM 5:30 PM	Dinner Break				
6:00 PM 6:15 PM	do				
6:30 PM					
6:45 PM 7:00 PM	do				
7:15 PM 7:30 PM	Leave for Next Community				
7:45 PM 8:00 PM	do				
8:15 PM					
8:30 PM 8:45 PM	do				
9:00 PM					
9:15 PM 9:30 PM	do				
9:45 PM 10:00 PM	Return Home/University				
10:15 PM					

Appendix 15b: Winter Daily Scheduling Template.

Date:

		Community	Name	Address	Telephone
10:00 AM	Leave U of A				
10:30 AM 11:00 AM	do/pu				
11:30 AM 12:00 PM	do/pu				
12:30 PM 1:00 PM	do/pu				
1:30 PM 2:00 PM	do/pu				
2:30 PM 3:00 PM	do/pu				
3:30 PM 4:00 PM	do/pu				
4:30 PM 5:00 PM 5:30 PM	Dinner Break				
6:00 PM 6:15 PM	do/pu				
6:30 PM					
6:45 PM 7:00 PM	do/pu				
7:15 PM 7:30 PM	Leave for Next Community				
7:45 PM 8:00 PM	do/pu				
8:15 PM					
8:30 PM 8:45 PM	do/pu				
9:00 PM 9:15 PM 9:30 PM	Return Home/University				

Appendix 16: Field Air Sampling Procedures.

Appendix 16a: Air Sampling Equipment.

- 3M OVM-3500:
    - sealed aluminum can
    - plastic snap lid
    - labels
    - PSD
    - elution cap
    - extraction tubule
- indoor mounting kit:
    - painter's tape (one inch)
    - string
    - scissors
    - measuring tape
- outdoor mounting kit:
    - mallet
    - Fall mounting stake
    - Winter mounting quadrapod
- transportation equipment:
    - Teflon tape (one inch)
    - insulated cooler
    - ice packs
- data log book and pencil
- laboratory 4C cooler

Appendix 16b: Indoor Air Sampling Procedure (after 3M, 1998b).

1. The participant's home is approached at the pre-scheduled time, and the field investigator(s) present picture identification to the participant.
2. A suitable sampling location is selected using the below parameters:
    - central living area
    - inside wall away from windows and doors
    - ~ 1.5 m above floor level
    - high human activity area
    - some air circulation
3. The indoor mounting kit is used to construct the indoor mounting apparatus which is attached to the wall in the selected sampling location.
4. Open the can containing the PSD and note the sampling start time. Do not remove the white film or plastic ring.
5. Remove the PSD from the can, affix one label to the can and the other to the back of the monitor.
6. Record the following information on the PSD labels and in the data log book:
    - monitor serial number
    - research identification number
    - sampling date
    - sampling start time
7. Attach the PSD to the indoor mounting apparatus using the alligator clip. This completes the deployment of the indoor PSD.
8. The participant's home is approached again at a pre-scheduled time, 24 (± 0.5) hours after deployment, and the field investigator(s) present picture identification to the participant.
9. Remove the PSD from the indoor mounting apparatus.
10. Remove the plastic ring and the white film from the PSD, and immediately snap the elution cap onto the PSD ensuring the two port plugs are secure.
11. Record the sampling finish time on the PSD labels and in the data log book.

12. Return the monitor to the original can it came in, close with the plastic lid, and seal the lid with Teflon tape.
13. Transfer the can containing the PSD to the insulated cooler where it's kept on ice for transport to the extraction laboratory.
14. The canned PSD is kept in a refrigerator at 4°C in the extraction laboratory for no longer than one week prior to extraction. This completes the retrieval of the indoor PSD.

Appendix 16c: Outdoor Air Sampling Procedure (after 3M, 1998b).

1. This outdoor air sampling procedure proceeds after the field investigator(s) completion of all of the necessary indoor procedures. This is intended to minimize participant burden.
2. A suitable sampling location is selected using the below parameters:
    - front yard
    - away from driveway
    - away from exhaust vents
    - ~ 1.2 m above ground level
3. The outdoor mounting apparatus is set-up in the above sampling location (Figure 7).
4. Open the can containing the PSD and note the sampling start time. Do not remove the white film or plastic ring.
5. Remove the PSD from the can, affix one label to the can and the other to the back of the monitor.
6. Record the following information on the PSD labels and in the data log book:
    - monitor serial number
    - research identification number
    - sampling date
    - sampling start time
7. Attach the PSD to the outdoor mounting apparatus using the alligator clip **(Figure 1)**. This completes the deployment of the outdoor PSD.
8. The participant's home is approached again at a pre-scheduled time, 24 (± 0.5) hours after deployment.
9. Remove the PSD from the outdoor mounting apparatus.
10. Remove the plastic ring and the white film from the PSD (Figure 6), and immediately snap the elution cap onto the PSD ensuring the two port plugs are secure (Figure 6).
11. Record the sampling finish time on the PSD labels and in the data log book.
12. Return the monitor to the original can it came in, close with the plastic lid, and seal the lid with Teflon tape.

13. Transfer the can containing the PSD to the insulated cooler where it's kept on ice for transport to the extraction laboratory.
14. The canned PSD is stored in a refrigerator at 4°C in the extraction laboratory for no longer than one week prior to extraction. This completes the retrieval of the outdoor PSD.

Appendix 17: Field Air Sampling Quality Assurance and Quality Control Procedures.

Field Blanks:

1. Open the can containing the PSD and remove it from the can.
2. Remove the plastic ring and the white film from the PSD, and immediately snap the elution cap onto the PSD ensuring the two port plugs are secure.
3. Affix one label to the can and the other to the back of the monitor.
4. Record the following information on the PSD labels and in the data log book:
    - monitor serial number
    - research identification number
    - sampling date
    - sampling start time
    - sampling finish time
5. Return the monitor to the original can it came in, close with the plastic lid, and seal the lid with Teflon tape.
6. During transport, keep the can containing the PSD on ice in the insulated cooler.
7. Return the canned PSD to the lab where it will be kept in a refrigerator and maintained at about 4°C until extraction.

Replicates:

The indoor air sampling procedure in Appendix 16b was performed in triplicate with the three PSDs placed greater than 10 cm but less than 2 m apart (Gagner, 1996), and with the PSDs being exposed as simultaneously as possible.

Appendix 18: Laboratory Desorption.

Appendix 18a: Laboratory Equipment.

- Basic Laboratory Equipment
  - Pyrex beaker, 250 mL (2)
  - wide mouth crucible (2)
  - Pyrex Flask and stopper, 150 mL (4)
  - glass graduated cylinder, 50 mL (1)
  - wide mouth funnel (2)
  - narrow mouth funnel (1)
- Laboratory Cleaning Equipment:
  - Glassware Cleaning Equipment
    - Lancer automatic dishwasher
    - Fisher Scientific Isotemp oven, held at ~175°C
  - Plasticware Cleaning Equipment
    - Fisher Scientific HPLC grade hexane
    - Fisher Scientific Isotemp 500 Series oven, held at ~40°C
  - Hamilton Syringe Cleaning Equipment
    - ultrasonic bath
    - deionized water
    - granular dish detergent
    - Fisher Scientific Isotemp 500 Series oven, held at ~40°C
  - Autosampler Vials Cleaning Equipment
    - Fisher Scientific HPLC grade hexane
    - Fisher Scientific Isotemp oven, held at ~175°C
    - Fisher Scientific Isotemp 500 Series oven, held at ~40°C
- Carbon Disulfide Purification Equipment:
  - ultra high purity nitrogen/high temperature (UHP/HT) oven
  - 50 mL (63 cm x 1 cm) Pyrex burette
  - Acros Organics molecular sieves, 13X, 8 to 12 mesh

- Fisher Scientific carbon disulfide, low benzene

- PSD Desorption Equipment:
  - Sigma MAP-1500, 1.5 mL fixed micropipette
  - Sigma 5000 uL disposable plastic pipette tips
  - Hamilton Gastight #1002 syringe, 2.5 mL
  - New Brunswick Scientific shaker table
  - Supelco clear screw-top autosampler vials with PTFE septa, 2 mL
  - Supelco autosampler vial trays
- Desorption Efficiency Equipment:
  - 3M OVM-3500
  - filter paper
  - Sigma MAP-1500, 1.5 mL fixed micropipette
  - Supelco EPA 524 Rev 4 Update Ketones Mix
  - Supelco EPA 524 Calibration Standards Kit
  - Supelco Appendix IX Volatile Calibration Mix 2
  - PSD desorption equipment

Appendix 18b: Laboratory Equipment Cleaning Procedures.

Glassware Cleaning Procedures (Froese, 1998)

1. Place glassware in Lancer dishwasher.
2. Enter program 7 on the dishwasher, press start and wait for completion of cycle.
3. Visually inspect glassware for cleanliness.
4. Place clean glassware in 175°C oven overnight.

Hexane Rinse Cleaning Procedures (Froese, 1998)

NOTE: Cleaning procedure for the autosampler vials, the micropipette disposable tips, and the burettes.

1. Rinse thoroughly with hexane.
2. Place autosampler vials in 175°C oven overnight.
3. Place autosampler lids in 40°C oven overnight.
4. Place micropipette's disposable tips in the 40°C oven overnight.

Hamilton Syringe Cleaning Procedures (Hamilton Tech. Services, 1998)

1. Fill the ultrasonic waterbath to 1 cm below the rim, add ~5 mL of granular detergent and turn on.
2. Remove the needle and plunger from the syringe, and carefully place all its parts in the waterbath for 15 to 30 minutes.
3. Remove the syringe parts from the waterbath and rinse them very well with deionized water.
4. Place in the 40°C oven overnight.

Appendix 18c: Laboratory Desorption Procedure (3M, 1997).

1. Remove canned PSD from laboratory refrigerator.
2. Remove PSD from can and inspect it to ensure that the elution cap and its two ports were firmly closed during storage, if not then note this.
3. In a fume hood, open the two ports, inject 1.5 mL of the purified carbon disulfide into the center port and immediately reseal both ports.
4. In a fume hood, gently agitate (125 rpm) the PSD on the shaker table.
5. After 30 minutes, open both ports, insert the decanting spout into the rim port, transfer the carbon disulfide to the autosampler vials and close both ports. This step should be carried out as quickly as possible to minimize volatilization.
6. Place the capped autosampler vial in its tray.
7. Repeat steps 1 to 6 for the remainder of the PSDs.
8. Store the tray of autosampler vials in a minus 50°C freezer until analysis.

Appendix 19: Laboratory Desorption Quality Assurance and Quality Control Procedures:

Appendix 19a: Carbon Disulfide Purification Procedure (Fellin, 1998).

1. In a fume hood, preheat the UHP/HT oven to 250°C.
2. Fill the oven to within ~2 cm of the rim with the molecular sieves.
3. Allow the molecular sieves to bake for at least 3 hours.
4. Remove the molecular sieves from the UHP/HT oven and allow to cool to room temperature.
5. In a fume hood, pack the two 50 mL burettes to within ~5 cm of the top with the thermally cleaned molecular sieves using the wide mouth funnel.
6. Add a 30 mL aliquot of carbon disulfide to each of the packed burettes using the narrow mouth funnel.
7. Pass the carbon disulfide through the burette at a rate of ~2 mL/minute.
8. Collect the carbon disulfide in a clean Pyrex flask, and then pass this carbon disulfide through the packed burette again.
9. Repeat steps 6 and 7 for another 30 mL aliquot of carbon disulfide.
10. After being used to clean 60 mL of carbon disulfide, the molecular sieves are to be thermally cleaned as described in steps 1 to 4.
11. Perform a GC/MS analysis of the purified and unpurified carbon disulfide in order to determine the effectiveness of the purification procedure and the consistency of the purified carbon disulfide from batch to batch.

Appendix 19b: Determination of Desorption Efficiency (after 3M, 1998a).

A. Recovered quantity of VOCs:

1. Remove the plastic ring and the Teflon barrier from the PSD.
2. Place a 2.5 cm filter paper on the spacer plate.
3. Attach the elution cap to the PSD ensuring a tight seal.
4. Spike the calculated quantity of organic mix onto the filter paper through the center port using a micropipette. The samples are to be prepared in duplicate from EPA Mix A with spikes of 1, 3, 5, and 7 microliters.
5. Close both ports immediately after spiking.
6. Allow the PSD to sit in a horizontal position at room temperature for approximately 24 hours.
7. After 24 hours, remove the filter paper and recap the PSD.
8. Proceed with the desorption procedure described in Appendix 18.
9. Determine the quantity of analyte recovered from the PSD by performing GC/MS analysis on the sample.

B. Spiked quantity of VOCs:

10. Using a micropipette, inject 1.5 mL of carbon disulfide into a 2 mL autosampler vial.
11. Immediately inject the calculated quantity of organic mix into the autosampler vial, cap and invert to mix. The spiked samples are prepared in duplicate as indicated in the table found in step (4) of this procedure.
12. Place the samples in the freezer.
13. Determine the quantity of analyte by performing GC/MS analysis on the sample.
14. Determine the recovery coefficient (r) by dividing the recovered quantity of the VOC by the spiked quantity of the VOC:

$$r = \left[\frac{Qr}{Qs}\right] \times 100 \text{, where} \qquad \textbf{Equation 11}$$

r = recovery coefficient, %

Qr = quantity of VOC recovered, ng/mL

Qs = quantity of VOC spike, ng/mL

Appendix 19c: Calibration of Hamilton Syringe or Micropipette.

1. Calibrate the mass balance.
2. Tare the mass balance with a clean 50 mL beaker.
3. Using the instrument being calibrated, add 1.5 mL of deionized water to the beaker and record the mass.
4. Tare the balance again with the first aliquot of water still in the beaker.
5. Add another 1.5 mL of deionized water to the beaker and record the mass.
6. Repeat steps 1 to 5 for a total of 7 trials.
7. Measure the temperature of the deionized water.
8. Calculate the volume of water actually dispensed from its mass and density at the measured temperature, and compare this to the amount that was supposed to be dispensed in order to determine the accuracy of the instrument.

Appendix 20: Microenvironmental Survey Questionnaire.

1. **Questionnaire: Household Characteristics (Fall)**
2. **Questionnaire: Household Activities (Fall)**
3. **Winter Questionnaire: Changes to Household Characteristics and Household Activities**

QUESTIONNAIRE: HOUSEHOLD CHARACTERISTICS

Research Id #: _____ Date received: _____

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators: Dr. Ken Froese
University of Alberta

Dr. Daniel Smith
University of Alberta

Field Investigators: Steven Probert
Capital Health Authority
492-8548 or 413-7927

Christine Byrne-Lewis
University of Alberta
492-8548

Instructions:

This questionnaire is for you to **complete before your second scheduled appointment**. Please answer the questions by printing in the spaces provided, or by placing a check-mark in the correct box.

Your answers help to determine things about your home that may affect indoor air quality. Before you mark a question as "unknown", please refer to the glossary of terms for unfamiliar words or contact Christine or Steven for help. You can contact them by telephone or wait for them to return for their next appointment.

Thank-you for your co-operation.

A. Household and Participant Identification:

The answers to questions 1 to 4 were provided on the consent form.

Please proceed to part B on the next page.

B. Household Habitants:

5. Who are the regular habitants of the house?

Person #	**1**	**2**	**3**
Name (optional)			
Age Category (* as below)			
Smoker (y/n)			
Student (y/n)			
Occupation			
Person #	**4**	**5**	**6**
Name (optional)			
Age Category (* as below)			
Smoker (y/n)			
Student (y/n)			
Occupation			

Age Categories: **1** is <1 year old
2 is 1to 5 years old
3 is 6 to 11 years old
4 is 12 to 19 years old
5 is over 20 years old

C. Type of House:

6. What type of a house do you live in?

☐ single family house ☐ duplex/triplex/quadruplex

☐ row/townhouse other _____

7. Which one of the following best describes your house?

☐ bungalow ☐ bilevel ☐ two story

☐ split level other _____

8. How big is the house, excluding the basement? Please circle the units used. _____square feet or square metres

9. Do you have a finished basement?

☐ yes ☐ no ☐ unknown

10. How big is the basement? Please circle the units used.

_____square feet or square metres

11. In what year was the house originally built? _____

12. Do you have an indoor swimming pool or indoor whirlpool?

☐ yes ☐ no ☐ unknown

D. Heating, Ventilation, and Air Conditioning Systems:

13. Does the house have an air conditioner?

☐ yes ☐ no ☐ unknown

If yes, what type? ☐ central ☐ room

If it's a room air conditioner, what room is it in? _____

14. Does the house have any fans for extra ventilation?

☐ yes ☐ no ☐ unknown

If yes, what type(s)? ☐ portable fan ☐ ceiling fan

Location(s)?_____

15. Does the house have an air purification system installed?

☐ yes ☐ no ☐ unknown

If yes, what type? _____

16. Does the house have any exhaust system(eg. range hood, fume hood)?

☐ yes ☐ no ☐ unknown

If yes, where is it? _____

Where does it vent to? ☐ outside ☐ inside

17. How do you heat your home? Indicate the type of heating systems in the below table, by marking the appropriate box with either 1^0 (main) or 2^0 (secondary) heating system. Also indicate the location of fireplaces, recreational stoves, and room heaters.

	Type of Fuel				**Location**
Type of System	n gas	elec	wood	other	
Forced air furnace					
Gravity furnace					
Radiant heat – wall					
Radiant heat – floor					
Fireplace/stove					
Room heater					
Portable heater					
Other _____					
Other _____					

18. Do you maintain the thermostat at a constant temperature throughout the day?

☐ yes ☐ no ☐ unknown

19. Does the heating system have a combustion air supply?

☐ yes ☐ no ☐ unknown

20. Does the heating system have a fresh air return?

☐ yes ☐ no ☐ unknown

E. Attached Structures:

21. Does the house have any attached structures?

☐ yes ☐ no ☐ unknown

If yes, what type(s)? ☐ garage ☐ shed/shop ☐ greenhouse ☐ other

If no then go to *Comments* on page 6.

22. Does the attached structure(s) have a door that opens into the house?

☐ yes ☐ no ☐ unknown

If yes, is this door(s) usually kept closed?

☐ yes ☐ no ☐ unknown

23. Does the attached structure have a heating system?

☐ yes ☐ no ☐ unknown

If yes, what type? Please use the categories listed in question (17).

_____

24. Does the attached structure have ventilation or exhaust system(s)?

☐ yes ☐ no ☐ unknown

If yes, what type?

☐ window/overhead door ☐ exhaust system ☐ fan

If exhaust, where does it vent to? ☐ outside ☐ inside

Comments:

GLOSSARY OF TERMS:

If the term you are looking for is not here or you still do not understand the question then please contact one of the investigators.

attached structure	a building which is physically connected to your home. This may include a garage, shed, greenhouse, etc.
combustion air supply	an (insulated) air duct/pipe which provides an air supply from outside to the furnace room. It is not directly attached to the furnace and it usually ends just above the floor with a perforated cap.
duct	a pipe which moves air through the house.
exhaust system	an electric fan which draws air out of an area and blows it outside (vents outside), or an electric fan which circulates the air through a filter and blows it back inside (vents inside).
fireplace/stove	a wood, gas, or coal fueled fire burning unit.
forced air furnace	a furnace that pushes warm air through the furnace ducts with an electric fan.
fresh air return	an (insulated) air duct which supplies fresh air from outside to the furnace. It is directly attached to the furnace's air intake duct.
gravity furnace	an older style furnace where the warm air rises naturally through the furnace's air ducts without the aid of a fan.
mechanical	a motorized system requiring power to run.
portable heater	a heater which is fueled by propane, kerosene, or

	electricity and can be easily moved from room to room.
radiant heat	a heating system which circulates hot water from a boiler through pipes located throughout the house. The heat from the hot water is given off (radiated) these pipes which either run along the base of the walls, or run underneath the floor.
room heater	a fixed heater located in a specific room which is intended to supplement the main heating system.
single family house	a structure which was originally designed to accommodate a single family.
vent	process of blowing air or fumes out the end of a pipe. If the air is blown to the outside then this is venting outside, if the air is blown back inside of the house then this is venting inside.
ventilation	the movement of air in a space. It can be either mechanical ventilation through the use of an electric fan, or it can be natural ventilation achieved by opening windows or doors.

QUESTIONNAIRE: HOUSEHOLD ACTIVITIES

Research Id #: _____ Interviewer: _____

Date: _____

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators: Dr. Ken Froese
University of Alberta

Dr. Daniel Smith
University of Alberta

Field Investigators: Steven Probert
Capital Health Authority
492-8548 or 413-7927

Christine Byrne-Lewis
University of Alberta
492-8548

F. Household Sources of VOCs:

25. Are all of your household appliances (cooking stove, hot water heater,clothes dryer, etc.) electric? If no, please complete the below table.

☐ yes ☐ no ☐ unknown

	Type of Fuel (✓)		
Type of Appliance	natural gas	other (specify)	location
cooking stove			
hot water heater			
clothes dryer			
other _____			

26. Do you ever use the cooking stove for heating your home?

☐ yes ☐ no ☐ unknown

27. Is the clothes dryer vented to the outside?

☐ yes ☐ no ☐ unknown

28. Is your home carpeted?

☐ yes ☐ no ☐ unknown

If no, then go to 31.

29. How much carpet would you guess your home has?

☐ <25% ☐ 25 to 50% ☐ 50 to 75% ☐ 75%

30. Has any part of the house had carpet installed within the past year?

☐ yes ☐ no ☐ unknown

If yes, than within past: ☐ 3 months ☐ 6 months

G. Household Activities:

31. Did anyone have the drapes, carpeting, or furniture professionally cleaned this past week?

☐ yes ☐ no ☐ unknown

32. Did anyone pick-up clothing from the dry-cleaners this past week?

☐ yes ☐ no ☐ unknown

33. Did anyone leave any windows open over the past 24 hours?

☐ yes ☐ no ☐ unknown

34. Do people smoke inside house or any of the attached structures?

☐ yes ☐ no ☐ unknown

35. Do you have any of the following items? Where is it stored? Did you use it recently, and if so where? Please complete the below table.

Item	Do you have? (y/n)	Storage location? Specify floor and room.	Recent use? (n/d/wk)	Where was recent use? Specify floor and room if different from storage location.
Gas, oil				
Propane				
Other fuels				
Vehicles				
Rec. vehicles				
Pesticides/ Fertilizers				
Paint or varnish				
Solvents				
Glues				
Dirty work clothing				
Clean/disinf. Agents				
Air deodorants				
Mothballs				
Cosmetic or hair products				
Aerosol spray				
Office equip.				

36. Did anyone perform one of the following activities within the house or attached structure in the past week?

- scale model building: ☐ yes ☐ no ☐ unknown
- artwork: ☐ yes ☐ no ☐ unknown
- furniture refinishing: ☐ yes ☐ no ☐ unknown
- metal working: ☐ yes ☐ no ☐ unknown
- welding: ☐ yes ☐ no ☐ unknown
- plastics work: ☐ yes ☐ no ☐ unknown
- auto body work: ☐ yes ☐ no ☐ unknown
- mechanical repairs: ☐ yes ☐ no ☐ unknown
- degreasing (oven/BBQ): ☐ yes ☐ no ☐ unknown
- **renovations/redecorating:**
  - painting/varnishing: ☐ yes ☐ no ☐ unknown
  - gluing/caulking: ☐ yes ☐ no ☐ unknown
  - re-flooring: ☐ yes ☐ no ☐ unknown
  - tiling: ☐ yes ☐ no ☐ unknown
  - plumbing: ☐ yes ☐ no ☐ unknown
  - new furniture: ☐ yes ☐ no ☐ unknown
  - other:_____

_____

_____

_____

WINTER QUESTIONNAIRE:
CHANGES TO HOUSEHOLD CHARACTERISTICS AND HOUSEHOLD ACTIVITIES

Research Id #: _____ Date received: _____

Title of Project: ***COMMUNITY SAMPLING OF VOLATILE ORGANIC COMPOUNDS IN THE CAPITAL HEALTH REGION***

Principal Investigator: Dr. Warren Kindzierski
University of Alberta
492-0247

Co-Investigators: Dr. Ken Froese
University of Alberta

Dr. Daniel Smith
University of Alberta

Field Investigators: Steven Probert
Capital Health Authority
492-8548 or 413-7927

Christine Byrne-Lewis
University of Alberta
492-8548

Instructions:

This questionnaire is to be completed through an interview by one of the field investigators. Please answer the questions by printing in the spaces provided, or by placing a check-mark in the correct box. The answers help to determine things about your home that may affect indoor air quality.

A. Changes to Household Characteristics:

1. Have any major renovations been performed on the house since our last interview this past fall?

☐ yes ☐ no ☐ unknown

If yes, please specify. _____

_____

_____

_____

2. Have any changes been made to the heating, ventilation or air conditioning systems since our last interview this past fall?

☐ yes ☐ no ☐ unknown

If yes, please specify. _____

_____

_____

_____

3. Have any major appliances been added, removed or changed in the house? ☐ yes ☐ no ☐ unknown

If yes, please specify. _____

_____

_____

_____

4. Have any major renovations been made to the attached structures or an attached structure been added since our last interview this past fall?

☐ yes ☐ no ☐ unknown

If yes, please specify._____

_____

_____

_____

5. Are the regular habitants of the house the same, or have any of them changed status? Please note changes in the below table.

Person #	**1**	**2**	**3**
Name (optional)			
Age Category (* as below)			
Smoker (y/n)			
Student (y/n)			
Occupation			

Age Categories: **1** is <1 year old
2 is 1to 5 years old
3 is 6 to 11 years old
4 is 12 to 19 years old
5 is over 20 years old

Comments:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

B. Household Activities:

6. Did anyone have the drapes, carpeting, or furniture professionally cleaned this past week?

☐ yes ☐ no ☐ unknown

7. Did anyone pick-up any clothing from the dry-cleaners this past week?

☐ yes ☐ no ☐ unknown

8. Did anyone leave any windows open over the past 24 hours?

☐ yes ☐ no ☐ unknown

9. Do people smoke inside house or any of the attached structures?

☐ yes ☐ no ☐ unknown

10. Do you have any of the following items? Where is it stored? Did you use it recently, and if so where? Please complete the below table.

Item	Do you have? (y/n)	Storage location? Specify floor and room.	Recent use? (n/d/wk)	Where was recent use? Specify floor and room if different from storage location.
Gas, oil				
Propane				
Other fuels				
Vehicles				
Rec. vehicles				
Pesticides/ Fertilizers				
Paint or varnish				
Solvents				
Glues				
Dirty work clothing				
Clean/disinf. agents				
Air deodorants				
Mothballs				
Cosmetic or hair products				
Aerosol spray				
Office equip.				

11. Did anyone perform one of the following activities within the house or attached structure in the past week?

- scale model building: ☐ yes ☐ no ☐ unknown
- artwork: ☐ yes ☐ no ☐ unknown
- furniture refinishing: ☐ yes ☐ no ☐ unknown
- metal working: ☐ yes ☐ no ☐ unknown
- welding: ☐ yes ☐ no ☐ unknown
- plastics work: ☐ yes ☐ no ☐ unknown
- auto body work: ☐ yes ☐ no ☐ unknown
- mechanical repairs: ☐ yes ☐ no ☐ unknown
- degreasing (oven/BBQ): ☐ yes ☐ no ☐ unknown
- **renovations/redecorating:**
  - painting/varnishing: ☐ yes ☐ no ☐ unknown
  - gluing/caulking: ☐ yes ☐ no ☐ unknown
  - re-flooring: ☐ yes ☐ no ☐ unknown
  - tiling: ☐ yes ☐ no ☐ unknown
  - plumbing: ☐ yes ☐ no ☐ unknown
  - new furniture: ☐ yes ☐ no ☐ unknown
  - other:_____

_____

_____

_____

Appendix 21: Questionnaire Field Procedures.

1. After receiving consent to participate during the first visit, the self-applied *Questionnaire: Household Characteristics* is given to each participant.
2. The questionnaire is briefly explained, the participant is advised that they do not have to complete questions they are not comfortable with and that it will be picked up during the scheduled sampling visits.
3. During the second visit, a field investigator inquires into whether the participants have any questions regarding the self-applied *Questionnaire: Household Characteristics.*
4. During the third visit, a field investigator inquires into whether the participants have any final questions regarding the self-applied *Questionnaire: Household Characteristics* and he retrieves it for his records.
5. Also during the third visit, a field investigator conducts an interview to complete the *Questionnaire: Household Activities.*
6. Lastly, during the fifth visit, a field investigator conducts an interview to complete the *Questionnaire: Changes to Household Characteristics and Household Activities.*

Appendix 22: Field Log Data.

Sampling	House	Badge	Time		Time	Temperature (C)			Relative Humidity (%)			Carbon Dioxide (ppm)		
Date	ID	ID	Start	Finish	(min.)	Start	Finish	Mean	Start	Finish	Mean	Start	Finish	Mean
09/21/98	12-9-1	KT9989	10.32	10.39	1447	19	20	20	48.4	50.5	49.5		560	280
09/21/98	12-9-2	KT9958	10.36	10.26	1430			0			0.0			0
09/21/98	4-16-1	TC0047	11.33	11.29	1436	20	21	21	43.8	44.8	44.3		580	290
09/21/98	4-16-2	TC0083	11.39	11.38	1439			0			0.0			0
09/21/98	2-14-1	TC0053	2.31	2.29	1438	21	21	21	33.8	32.3	33.1		476	238
09/21/98	2-14-2	TC0051	2.35	2.32	1437			0			0.0			0
09/21/98	15-19-1	TC0081	4.22	4.25	1443	22	22	22	45.7	45.9	45.8		767	384
09/21/98	15-19-2	TC0050	4.39	4.45	1446			0			0.0			0
09/21/98	10-1-1	KT9962	6.01	6.03	1442	22	20	21	33.6	37.3	35.5		500	250
09/21/98	10-1-2	KT9988	6.04	6.05	1441			0			0.0			0
09/21/98	10-2-1	TC0080	6.28	6.22	1434	25	20	23	36.4	44.8	40.6		722	361
09/21/98	10-2-2	TC0043	6.36	6.29	1433			0			0.0			0
09/21/98	5-24-1	TC0046	7.51	7.49	1438	24	23	24	33.5	39.1	36.3		483	242
09/21/98	5-24-2	TC0079	7.54	7.50	1436			0			0.0			0
09/21/98	8-32-1	KT9957	8.28	8.35	1447	24	22	23	35.3	36.4	35.9		530	265
09/21/98	8-32-2	KT9990	8.43	8.38	1435			0			0.0			0
09/21/98	5-25-1	KT9991	9.09	8.57	1388	25	23	24	46.0	45.7	45.9		740	370
09/21/98	5-25-2	KT9961	9.15	9.00	1425			0			0.0			0
09/23/98	9-4-1	JA9809	10.32	10.25	1433	21	20	21	50.7	58.9	54.8	685	648	667
09/23/98	9-4-3	JA9840	10.35	10.27	1432	21	20	21	50.7	58.9	54.8	685	648	667
09/23/98	9-4-5	JA9860	10.39	10.29	1430	21	20	21	50.7	58.9	54.8	685	648	667
09/23/98	9-4-2	JA9700	10.52	10.45	1433			0			0.0			0
09/23/98	14-29-1	JA9617	11.29	11.32	1443	20	21	21	62.5	70.0	66.3	1600	1782	1691
09/23/98	14-29-2	JA9775	11.36	11.49	1453			0			0.0			0
09/23/98	7-34-1	JA9679	3.41	3.39	1438	24	22	23	45.5	52.9	49.2	930	974	952
09/23/98	7-34-2	JA9682	3.52	3.54	1442			0			0.0			0
09/23/98	1-12-1	JA9723	6.03	6.08	1445	22	24	23	47.3	51.2	49.3	1015	840	928
09/23/98	1-12-2	JA9693	6.07	6.14	1447			0			0.0			0
09/23/98	3-10-1	JA9641	6.46	6.41	1435	22	22	22	53.4	56.3	54.9	1005	900	953
09/23/98	3-10-2	JA9812	6.51	6.53	1442			0			0.0			0
09/23/98	11-5-1	JA9728	7.51	7.49	1438	21	19	20	35.4	46.0	40.7	925	720	823
09/23/98	11-5-2	JA9722	7.58	7.59	1441			0			0.0			0
09/23/98	11-6-1	JA9763	8.27	8.29	1442	22	20	21	48.0	48.0	48.0	705	560	633
09/23/98	11-6-2	JA9665	8.36	8.40	1444			0			0.0			0
09/23/98	11-7-1	JA9784	8.57	9.00	1483	21	20	21	51.6	54.4	53.0	804	780	792
09/23/98	11-7-2	JA9613	9.04	9.07	1443			0			0.0			0
09/24/98	17-80-1	JA9813	7.53		687	19	19	19	46.0	46.0	46.0	720	720	720
09/25/98	12-30-1	JA9786	3.45	3.35	1430	19	20	20	75.0	37.3	56.2	813	570	692
09/25/98	12-30-2	JA9732	3.51	3.41	1430			0			0.0			0
09/25/98	12-3-1	JA9749	6.09	6.08	1439	22	20	21	74.6	36.7	55.7	934	475	705
09/25/98	12-3-2	JA9663	6.17	6.16	1439			0			0.0			0
09/25/98	14-28-1	JA9688	6.47	6.43	1436	22	22	22	58.0	36.2	47.1	789	560	675
09/25/98	14-28-2	JA9662	6.55	6.48	1433			0			0.0			0
09/25/98	4-22-1	JA9773	7.48	7.47	1439	20	23	22	60.0	45.2	52.6	1000	628	814
09/25/98	4-22-2	JA9822	7.57	8.01	1484			0			0.0			0
09/25/98	6-40-1	JA9867	8.31	8.30	1439	19	22	21	66.7	46.2	56.5	1127	724	926
09/25/98	6-40-2	JA9815	8.38	8.35	1437			0			0.0			0
09/25/98	2-56-1	JA9694	9.02	9.04	1442	20	20	20	56.2	45.8	51.0	682	682	682
09/25/98	2-56-2	JA9849	9.10	9.09	1439			0			0.0			0
09/28/98	2-15-1	JA9698	1.32	1.28	1436	21	21	21	57.0	48.5	52.8	893	1200	1047
09/28/98	2-15-2	JA8875	1.38	1.33	1435			0			0.0			0
09/28/98	4-37-1	JC7901	6.06	6.11	1445	20	21	21	56.7	55.6	56.2	1168	1020	1094
09/28/98	4-37-2	JP2133	6.12	6.13	1441			0			0.0			0
09/28/98	7-35-1	JA9787	6.45	6.49	1444	19	17	18	47.8	45.5	46.7	923	589	756
09/28/98	7-35-2	JA9807	6.51	6.56	1445			0			0.0			0
09/28/98	15-18-1	JA9818	7.48	7.46	1438	22	20	21	45.4	45.0	45.2	500	537	519
09/28/98	15-18-2	JA9800	7.53	7.52	1439			0			0.0			0

Sampling	House	Badge	Time		Time	Temperature (C)			Relative Humidity (%)			Carbon Dioxide (ppm)		
Date	ID	ID	Start	Finish	(min.)	Start	Finish	Mean	Start	Finish	Mean	Start	Finish	Mean
09/28/98	11-8-1	JA9793	8.30	8.34	1444	23	20	22	51.1	52.2	51.7	823	1002	913
09/28/98	11-8-2	JA9794	8.36	8.37	1441			0			0.0			0
09/28/98	16-21-1	JA9801	9.03	9.02	1439	22	19	21	53.7	45.9	49.8	800	765	783
09/28/98	16-21-2	JA9868	9.09	9.07	1438			0			0.0			0
09/30/98	10-43-1	JP2231	10.35	10.32	1437	20	19	20	49.0	54.4	51.7	597	709	653
09/30/98	10-43-2	JP2251	10.50	10.47	1437			0			0.0			0
09/30/98	10-43-4	JP2211	10.51	10.48	1437			0			0.0			0
09/30/98	10-43-6	JP1799	10.52	10.49	1437			0			0.0			0
09/30/98	13-47-1	JP1831	11.40	11.31	1431	18	19	19	48.1	45.6	46.9	642	615	629
09/30/98	13-47-2	JP1864	11.48	11.38	1430			0			0.0			0
09/30/98	16-20-1	JA9707	6.09	6.07	1438	19	20	20	29.9	31.5	30.7	445	433	439
09/30/98	16-20-2	JA9695	6.14	6.11	1437			0			0.0			0
09/30/98	16-27-1	JA9810	6.48	6.47	1439	20	20	20	45.0	39.0	42.0	573	490	532
09/30/98	16-27-2	JA9625	6.54	6.53	1439			0			0.0			0
09/30/98	5-26-1	JC7937	7.48	7.47	1439	20	22	21	45.7	45.4	45.6	740	582	661
09/30/98	5-26-2	JC7924	7.54	7.51	1437			0			0.0			0
09/30/98	7-36-1	JC7861	8.09		631	21		11	46.3		23.2	541		271
09/30/98	7-36-2	JC7940	8.16	8.22	1446			0			0.0			0
10/02/98	4-59-1	JC7805	5.59	5.59	1440	21	20	21	45.9	56.0	51.0	585	813	699
10/02/98	4-59-2	JC7873	6.09	6.16	1447			0			0.0			0
10/03/98	17-81-2	JD2694	6.20	6.21	1441			0			0.0			0
10/05/98	6-54-1	JP2656	10.40	---	---	17		9	43.6		21.8	445		223
10/05/98	6-54-2	JP2668	10.52	10.42	1430			0			0.0			0
10/05/98	8-33-1	JD2581	11.09	11.11	1442	19	18	19	50.4	46.0	48.2	566	557	562
10/05/98	8-33-2	JD2541	11.20	11.22	1442			0			0.0			0
10/05/98	13-17-1	JC7947	2.36	2.42	1446	22	22	22	40.2	34.2	37.2	630	691	661
10/05/98	13-17-2	JC7897	2.51	3.10	1499			0			0.0			0
10/05/98	3-11-1	KU9264	6.32	6.17	1425	20	19	20	46.2	39.0	42.6	863	1129	996
10/05/98	3-11-2	TC3433	6.36	6.23	1427			0			0.0			0
10/05/98	5-39-1	JD2591	6.49	6.49	1440	22	23	23	46.0	36.4	41.2	749	557	653
10/05/98	5-39-2	JD2609	6.54	6.54	1440			0			0.0			0
10/05/98	12-61-1	TC3436	8.00	8.08	1448	19	20	20	51.5	37.0	44.3	1090	540	815
10/05/98	12-61-2	KB9938	8.06	8.17	1451			0			0.0			0
10/07/98	13-63-1	JC7774	12.50	12.37	1427	21	19	20	45.6	50.4	48.0	771	803	787
10/07/98	13-63-2	JP2281	1.03	1.02	1439			0			0.0			0
10/07/98	13-49-1	JP1859	1.25	1.09	1424	21	21	21	45.2	46.3	45.8	730	615	673
10/07/98	13-49-3	JP2123	1.27	1.11	1424	21	21	21	45.2	46.3	45.8	730	615	673
10/07/98	13-49-5	JP2459	1.31	1.13	1422	21	21	21	45.2	46.3	45.8	730	615	673
10/07/98	13-49-2	JP2496	1.35	1.33	1438			0			0.0			0
10/07/98	10-44-1	JD2500	6.49	6.49	1440	24	21	23	54.5	64.0	59.3	1515	930	1223
10/07/98	10-44-2	JD2621	6.54	6.57	1443			0			0.0			0
10/07/98	6-52-1	JD2604	7.47	7.47	1440	22	20	21	46.0	61.6	53.8	762	703	733
10/07/98	6-52-2	JD2508	7.52	7.55	1443			0			0.0			0
10/07/98	6-41-1	JP2177	8.31	8.28	1437	20	19	20	43.3	62.5	52.9	673	594	634
10/07/98	6-41-2	JP2169	8.38	8.33	1435			0			0.0			0
10/07/98	4-38-1	JP2620	9.04	8.49	1385	22	18	20	48.3	53.0	50.7	653	519	586
10/07/98	4-38-2	JP2530	9.10	8.59	1389			0			0.0			0
10/08/98	17-82-1	JP2705	6.51	6.51	1440	21		11	64.0		32.0	930		465
10/13/98	15-46-1	JD2608	1.44	1.38	1434	18	20	19	57.6	60.0	58.8	648	666	657
10/13/98	15-46-2	JD2645	1.51	1.57	1446			0			0.0			0
10/13/98	9-31-1	TK5855	2.19	2.13	1434	19	20	20	45.2	47.9	46.6	535	670	603
10/13/98	9-31-2	JD2552	2.30	2.31	1441			0			0.0			0
10/13/98	9-31-4	JP1924	2.30	2.31	1441			0			0.0			0
10/13/98	9-31-6	JP1699	2.30	2.32	1442			0			0.0			0
10/13/98	6-53-1	JD2562	6.19	6.12	1433	20	20	20	66.0	69.6	67.8	710	812	761
10/13/98	6-53-2	JD2488	6.27	6.31	1444			0			0.0			0
10/13/98	7-36-1	JD2432	6.50	6.43	1433	19	18	19	55.0	47.0	51.0	593	632	613
10/13/98	7-36-2	JP2497	6.59	7.02	1483			0			0.0			0

Sampling	House	Badge	Time		Time	Temperature (C)			Relative Humidity (%)			Carbon Dioxide (ppm)		
Date	ID	ID	Start	Finish	(min.)	Start	Finish	Mean	Start	Finish	Mean	Start	Finish	Mean
10/13/98	15-42-1	JP2522	7.47	7.49	1442	18	20	19	55.6	51.4	53.5	578	649	614
10/13/98	15-42-2	JP2233	7.53	8.06	1493			0			0.0			0
10/13/98	9-45-*1	JP2280	8.39	8.32	1433	20	20	20	57.1	45.7	51.4	671	490	581
10/13/98	9-45-2	JP1904	8.45	8.45	1440			0			0.0			0
10/13/98	14-50-1	JP2274	9.03	9.00	1437	19	20	20	59.5	66.2	62.9	948	925	937
10/13/98	14-50-2	JP2199	9.17	9.13	1436			0			0.0			0
10/14/98	17-83-1	JP2523	1.41	1.41	1440	20	20	20	60.0	60.0	60.0	666	666	666
10/15/98	6-64-1	JP1850	6.46	6.48	1442	17	15	16	59.2	56.5	57.9	820	940	880
10/15/98	6-64-2	JP1782	7.00	7.11	1451			0			0.0			0
10/20/98	3-58-1	JD2610	2.41	2.33	1432	19	19	19	46.6	46.1	46.4	1240	1310	1275
10/20/98	3-58-3	JD2582	2.42	2.34	1432	19	19	19	46.6	46.1	46.4	1240	1310	1275
10/20/98	3-58-5	TK6026	2.44	2.35	1431	19	19	19	46.6	46.1	46.4	1240	1310	1275
10/20/98	3-58-2	TK5987	2.52	2.51	1439			0			0.0			0
10/20/98	2-55-1	TK5999	3.33	3.33	1440	19	18	19	46.1	45.6	45.9	960	1230	1095
10/20/98	2-55-2	TK5860	3.45	3.51	1446			0			0.0			0
10/20/98	10-60-1	JP1875	9.14	9.05	1431	22	22	22	46.0	46.4	46.2	1120	983	1052
10/20/98	10-60-2	JP1851	9.28	9.22	1434			0			0.0			0
10/21/98	17-84-2	TK6112	2.53	2.53	1440			0			0.0			0
10/22/98	2-57-1	TK5873	10.39	10.41	1442	20	20	20	45.3	36.8	41.1	724	575	650
10/22/98	2-57-2	TK5919	10.45	10.49	1444			0			0.0			0
10/22/98	1-65-1	TK5882	11.30	11.16	1426	20	19	20	45.7	46.2	46.0	696	653	675
10/22/98	1-65-2	TK5905	11.35	11.28	1433			0			0.0			0
10/27/98	13-48-1	TK6427	2.35	2.36	1441	23	20	22	33.1	50.1	41.6	475	551	513
10/27/98	13-48-2	KU6353	2.46	3.01	1495			0			0.0			0
10/27/98	13-48-4	TU2794	2.46	3.02	1496			0			0.0			0
10/27/98	13-48-6	TK6338	2.48	3.03	1495			0			0.0			0
10/27/98	16-51-1	KU7940	6.03	6.02	1439	22	18	20	45.9	53.6	49.8	770	670	720
10/27/98	16-51-2	KT9960	6.11	6.15	1444			0			0.0			0
10/28/98	17-85-1	JP2637	2.37	2.37	1440			0			0.0			0
11/05/98	4-23-1	KU6537	1.47	1.39	1432	23	19	21	44.2	51.0	47.6	760	869	815
11/05/98	4-23-3	TC3439	1.47	1.39	1432	23	19	21	44.2	51.0	47.6	760	869	815
11/05/98	4-23-5	TK5886	1.47	1.39	1432	23	19	21	44.2	51.0	47.6	760	869	815
11/05/98	4-23-2	TK5887	1.58	1.46	1428			0			0.0			0
11/06/98	17-86-1	TU2588	1.34	1.34	1440	19	19	19	51.0	51.0	51.0	869	869	869
01/11/99	1-65-1	TK6242	10.43	10.33	1430	16	16	16	29.5	35.1	32.3	890	815	853
01/11/99	1-65-2	TK6102	10.53	10.46	1433			0			0.0			0
01/11/99	2-57-1	TK6396	11.28	11.29	1441	19	18	19	25.5	32.0	28.8	548	590	569
01/11/99	2-57-2	TK6214	11.39	11.42	1443			0			0.0			0
01/11/99	2-15-1	JP1756	2.34	2.35	1441	19	21	20	60.2	44.3	52.3		1070	535
01/11/99	2-15-2	TK6248	2.42	2.51	1449			0			0.0			0
01/11/99	1-12-1	TK6345	6.02	6.02	1440	19	19	19	28.2	27.6	27.9	638	697	668
01/11/99	1-12-2	TK6257	6.11	6.15	1444			0			0.0			0
01/11/99	4-37-1	TU2567	6.51	6.51	1440	18	18	18	56.5	46.1	51.3	980	810	895
01/11/99	4-37-2	JP1889	7.01	6.57	1396			0			0.0			0
01/11/99	13-49-1	TC3663	7.50	7.55	1445	20	20	20	30.4	29.0	29.7	588	620	604
01/11/99	13-49-0	TC3670	8.01	8.10	1449			0			0.0			0
01/11/99	13-49-2	TK5869	8.04	8.11	1447			0			0.0			0
01/11/99	10-60-1	TK6096	8.32	8.32	1440	18	20	19	49.5	45.4	47.5	882	1020	951
01/11/99	10-60-2	TK6233	8.41	8.44	1443			0			0.0			0
01/13/99	13-47-1	TC3490	10.36	10.31	1435	17	17	17	26.9	24.3	25.6	538	586	562
01/13/99	13-47-2	TC3483	10.43	13.47	1744			0			0.0			0
01/13/99	13-48-1	TC3487	11.36	11.32	1436	22	19	21	32.4	34.2	33.3	540	605	573
01/13/99	13-48-3	TC3480	11.37	11.31	1434	22	19	21	32.4	34.2	33.3	540	605	573
01/13/99	13-48-5	TC3489	11.38	11.31	1433	22	19	21	32.4	34.2	33.3	540	605	573
01/13/99	13-48-2	TC3477	11.50	11.45	1435			0			0.0			0
01/13/99	9-31-1	TC3478	1.33	1.30	1437	22	21	22	27.5	33.0	30.3	740	651	696
01/13/99	9-31-2	TC3481	1.42	1.46	1444			0			0.0			0

Sampling	House	Badge	Time		Time	Temperature (C)			Relative Humidity (%)			Carbon Dioxide (ppm)		
Date	ID	ID	Start	Finish	(min.)	Start	Finish	Mean	Start	Finish	Mean	Start	Finish	Mean
01/13/99	13-63-1	TC3471	3.33	3.27	1434	17	18	18	31.5	30.7	31.1	464	750	607
01/13/99	13-63-2	TC3474	3.43	3.40	1437			0			0.0			0
01/13/99	10-2-1	TC3657	6.03	6.00	1437	17	19	18	47.5	44.8	46.2	1170	1280	1225
01/13/99	10-2-2	TC3667	6.11	6.12	1441			0			0.0			0
01/13/99	9-45-1	TC3658	6.38	6.33	1435	18	20	19	45.4	45.4	45.4	579	580	580
01/13/99	9-45-2	TC3661	6.44	6.45	1441			0			0.0			0
01/13/99	7-34-1	TC3664	7.47	7.47	1440	20	19	20	45.1	45.6	45.4	945	1020	983
01/13/99	7-34-2	TC3660	7.57	8.08	1491			0			0.0			0
01/13/99	3-10-1	TC3669	8.31	8.34	1443	19	20	20	32.3	43.8	38.1	966	995	981
01/13/99	3-10-2	TC3666	8.43	8.45	1442			0			0.0			0
01/15/99	13-17-1	TK6076	7.51	7.47	1436	20	19	20	24.4	23.2	23.8	620	533	577
01/15/99	13-17-2	TK5906	8.15	8.09	1434			0			0.0			0
01/15/99	11-8-1	JP1730	8.30	8.30	1440	19	20	20	46.1	45.3	45.7	927	1126	1027
01/15/99	11-8-2	JP1901	8.37	8.47	1450			0			0.0			0
01/16/99	17-87-1	TK6337	7.48	7.48	1440	19	19	19	23.2	23.2	23.2	533	533	533
01/18/99	10-43-1	TC3398	10.32	10.34	1442	17	18	18	30.3	33.3	31.8	646	780	713
01/18/99	10-43-2	TC3388	10.44	10.52	1448			0			0.0			0
01/18/99	16-20-1	TC3384	2.25	2.32	1447	19	20	20	28.3	26.2	27.3	647	452	550
01/18/99	16-20-2	TC3376	2.38	2.49	1451			0			0.0			0
01/18/99	15-19-1	TC3375	3.05	3.19	1454	17	20	19	48.3	46.1	47.2	896	895	896
01/18/99	15-19-2	TC3379	3.14	3.38	1464			0			0.0			0
01/18/99	11-7-1	TC3396	6.01	6.03	1442	19	18	19	35.3	59.1	47.2	1170	1128	1149
01/18/99	11-7-2	TC3397	6.07	6.10	1443			0			0.0			0
01/18/99	10-44-1	TC3391	6.55	6.37	1422	19	20	20	46.7	34.1	40.4	955	752	854
01/18/99	10-44-2	TC3460	7.08	6.57	1389			0			0.0			0
01/18/99	4-38-1	TU2609	7.57	7.49	1432	16	17	17	27.1	32.6	29.9	748	676	712
01/18/99	4-38-2	TC3461	8.12	8.16	1444			0			0.0			0
01/18/99	5-26-1	TC3486	8.37	8.30	1433	20	20	20	36.2	29.3	32.8	729	822	776
01/18/99	5-26-2	TC3484	8.52	8.45	1433			0			0.0			0
01/20/99	2-55-1	TC3654	10.41	10.42	1441	15	19	17	46.0	51.0	48.5	924	785	855
01/20/99	2-55-2	TC3648	10.59	10.58	1439			0			0.0			0
01/20/99	4-23-1	TC3651	11.37	11.35	1438	17	19	18	44.4	35.4	39.9	608	522	565
01/20/99	4-23-2	TC3520	11.48	11.49	1441			0			0.0			0
01/20/99	4-59-1	TC3524	12.20	12.18	1438	18	20	19	30.4	22.2	26.3	640	583	612
01/20/99	4-59-2	TC3530	12.30	12.34	1444			0			0.0			0
01/20/99	5-39-1	TC3517	6.24	6.27	1443	20	21	21	43.7	30.0	36.9	568	598	583
01/20/99	5-39-2	TC3508	6.29	6.42	1453			0			0.0			0
01/20/99	5-25-1	TC3514	6.41	6.50	1449	20	20	20	38.3	28.0	33.2	528	620	574
01/20/99	5-25-2	TC3511	6.53	7.20	1507			0			0.0			0
01/20/99	16-21-1	TC3533	7.51	8.12	1501	20	21	21	46.3	32.0	39.2	1038	928	983
01/20/99	16-21-2	TC3521	7.59	8.24	1505			0			0.0			0
01/20/99	10-1-1	TC3527	8.20	8.50	1470	19	18	19	44.9	28.0	36.5	720	810	765
01/20/99	10-1-2	TC3387	8.30	8.57	1467			0			0.0			0
01/21/99	17-88-1	TC3463	12.20	12.20	1440			0			0.0			0
01/22/99	11-6-1	TC3473	6.08	6.01	1433	20	18	19	24.5	37.8	31.2	622	1072	847
01/22/99	11-6-2	TC3470	6.17	6.23	1446			0			0.0			0
01/22/99	11-6-4	TC3650	6.17	6.23	1446			0			0.0			0
01/22/99	11-6-6	TC3653	6.17	6.23	1446			0			0.0			0
01/22/99	12-3-1	TC3644	6.49	6.49	1440	20	19	20	45.1	24.4	34.8	780	792	786
01/22/99	12-3-2	TC3647	6.58	7.13	1495			0			0.0			0
01/22/99	6-64-1	TC3642	7.45	7.50	1445	18	22	20	36.1	16.0	26.1	666	940	803
01/22/99	6-64-2	TC3641	8.12	8.08	1436			0			0.0			0
01/25/99	8-33-1	TC3957	10.33	10.33	1440	19	19	19	34.9	32.1	33.5	634	618	626
01/25/99	8-33-2	TC3960	10.40	10.44	1444			0			0.0			0
01/25/99	3-58-1	TC3970	11.51	11.34	1423	20	17	19	34.2	49.8	42.0	840	1297	1069
01/25/99	3-58-3	TC3645	11.52	11.34	1422	20	17	19	34.2	49.8	42.0	840	1297	1069

Sampling	House	Badge	Time		Time	Temperature (C)			Relative Humidity (%)			Carbon Dioxide (ppm)		
Date	ID	ID	Start	Finish	(min.)	Start	Finish	Mean	Start	Finish	Mean	Start	Finish	Mean
01/25/99	3-58-5	TC3966	11.52	11.35	1423	20	17	19	34.2	49.8	42.0	840	1297	1069
01/25/99	3-58-2	TC3963	12.02	11.54	1392			0			0.0			0
01/25/99	6-40-1	TC0205	6.10	6.23	1453	16	16	16	45.7	32.3	39.0	804	730	767
01/25/99	6-40-2	TC0209	6.19	6.34	1455			0			0.0			0
01/25/99	5-24-1	TC0208	6.51	6.51	1440	20	21	21	27.2	45.2	36.2	750	716	733
01/25/99	5-24-2	TC0204	7.01	7.01	1440			0			0.0			0
01/25/99	16-27-1	TC0202	7.56	7.49	1433	18	15	17	33.3	30.0	31.7	595	469	532
01/25/99	16-27-2	TC0203	8.06	8.01	1435			0			0.0			0
01/25/99	15-46-1	TC0200	8.32	8.30	1438	19	19	19	31.9	31.3	31.6	554	687	621
01/25/99	15-46-2	TC0201	8.39	8.42	1443			0			0.0			0
01/27/99	9-4-1	TC0207	10.35	10.34	1439	17	18	18	33.9	33.3	33.6	630	714	672
01/27/99	9-4-2	TC0206	10.43	10.51	1448			0			0.0			0
01/27/99	6-52-1	KT9900	7.49	7.47	1438	16	17	17	41.9	30.7	36.3	854	970	912
01/27/99	6-52-2	KT9901	7.55	8.07	1492			0			0.0			0
01/27/99	6-41-1	KT9896	8.33	8.29	1436	15	17	16	47.5	21.5	34.5	826	735	781
01/27/99	6-41-2	KT9902	8.39	8.44	1445			0			0.0			0
01/28/99	17-89-1	KT9987	7.49	7.49	1440	17	17	17	30.7	31.0	30.9	970	970	970
01/28/99	17-90-2	KT9898	8.08	8.08	1440			0			0.0			0
01/29/99	6-53-1	KT9891	5.59	6.03	1484	17	19	18	46.1	34.7	40.4	865	797	831
01/29/99	6-53-2	KT9895	6.04	6.17	1453			0			0.0			0
01/29/99	4-22-1	KT9899	6.45	6.40	1435	20	19	20	50.1	52.6	51.4	755	810	783
01/29/99	4-22-2	KT9894	6.54	6.56	1442			0			0.0			0
02/01/99	15-42-1	TC3961	10.41	10.36	1435	18	18	18	30.2	23.0	26.6	655	693	674
02/01/99	15-42-2	TC3964	10.49	10.54	1445			0			0.0			0
02/01/99	14-29-1	KT9987	11.11	11.32	1461	20	18	19	46.8	32.7	39.8	1265	845	1055
02/01/99	14-29-2	KT9985	11.16	11.11	1435			0			0.0			0
02/01/99	11-5-1	TC3971	6.02	6.00	1438	18	18	18	44.9	28.8	36.9	620	670	645
02/01/99	11-5-2	TC3968	6.06	6.16	1450			0			0.0			0
02/01/99	14-28-1	KT9982	6.51	6.33	1422	20	18	19	45.0	18.3	31.7	665	560	613
02/01/99	14-28-2	TC3958	6.58	6.49	1431			0			0.0			0
02/01/99	7-36-1	KT9980	7.47	7.35	1428	18	18	18	28.7	18.3	23.5	657	700	679
02/01/99	7-36-2	KT9981	7.51	7.53	1442			0			0.0			0
02/02/99	17-91-2	KT9978	11.16	11.16	1440			0			0.0			0
02/03/99	2-14-1	TC3464	10.34	10.37	1443	18	16	17	44.8	29.6	37.2	850	1070	960
02/03/99	2-14-2	TC3383	10.48	11.06	1498			0			0.0			0
02/03/99	2-14-4	TC3386	10.48	11.07	1499			0			0.0			0
02/03/99	2-14-6	KT9983	10.48	11.05	1497			0			0.0			0
02/03/99	2-14-8u	KT9986	10.48	11.05	1497			0			0.0			0
02/03/99	2-14-10u	TC3466	10.48	11.06	1498			0			0.0			0
02/03/99	2-14-12u	TC3467	10.48	11.05	1497			0			0.0			0
02/03/99	3-11-1	TC3381	6.17	6.05	1428	16	16	16	34.1	22.5	28.3	903	848	876
02/03/99	3-11-2	KT9979	6.28	6.20	1432			0			0.0			0
02/03/99	8-32-1	TC3377	6.52	6.42	1430	18	19	19	19.8	18.5	19.2	494	692	593
02/03/99	8-32-2	TC3380	7.03	6.50	1387			0			0.0			0
02/03/99	16-51-1	TC4061	7.58	7.47	1429	20	20	20	19.1	17.6	18.4	764	856	810
02/03/99	16-51-2	TC3373	8.08	8.07	1439			0			0.0			0
02/05/99	12-30-1	TC3385	1.29	1.28	1439	18	20	19	24.1	50.9	37.5	855	1713	1284
02/05/99	12-30-2	TC3382	1.34	1.56	1462			0			0.0			0
02/08/99	4-16-1	TC3351	10.39	10.38	1439	18	16	17	26.5	27.0	26.8	814	814	814
02/08/99	4-16-3	TC3352	10.40	10.39	1439	18	16	17	26.5	27.0	26.8	814	814	814
02/08/99	4-16-5	TC4050	10.41	10.40	1439	18	16	17	26.5	27.0	26.8	814	814	814
02/08/99	4-16-2	TC3350	10.50	10.59	1449			0			0.0			0
02/08/99	7-66-1	TC4054	2.32	2.31	1439	17	17	17	20.5	34.8	27.7	686	887	787
02/08/99	7-66-2	TC4057	2.45	2.44	1439			0			0.0			0
02/08/99	2-56-1	TC3378	6.35	6.40	1445	18	19	19	32.9	19.9	26.4	780	612	696
02/08/99	2-56-2	TC3374	6.48	6.58	1450			0			0.0			0

Sampling	House	Badge	Time		Time	Temperature (C)			Relative Humidity (%)			Carbon Dioxide (ppm)		
Date	ID	ID	Start	Finish	(min.)	Start	Finish	Mean	Start	Finish	Mean	Start	Finish	Mean
02/08/99	12-61-1	TC4066	7.49	7.45	1436	17	18	18	36.9	22.7	29.8	1045	1010	1028
02/08/99	12-61-2	TC4060	8.02	8.01	1439			0			0.0			0
02/08/99	15-50-1	TC4047	8.29	8.26	1437	16	18	17	24.7	27.2	26.0	945	1153	1049
02/08/99	15-50-2	TC4048	8.41	8.43	1442			0			0.0			0
02/09/99	17-92-1	TC4051	10.41	10.41	1440	16	16	16	27.0	27.0	27.0	874	814	844
02/12/99	12-9-1	TC3485	6.43	6.36	1433	16	18	17	33.6	43.5	38.6	776	1013	895
02/12/99	12-9-2	TC3488	6.57	7.05	1488			0			0.0			0
02/12/99	12-9-4	TC3354	6.57	7.05	1488			0			0.0			0
02/12/99	12-9-6	TC3349	6.57	7.04	1487			0			0.0			0
02/12/99	12-9-8u	TC4049	6.57	7.05	1488			0			0.0			0
02/12/99	12-9-10u	TC3356	6.57	7.04	1487			0			0.0			0
02/12/99	12-9-12u	TC3348	6.57	7.04	1487			0			0.0			0
02/12/99	15-18-1	TC3357	7.54	7.37	1423	19	19	19	18.5	24.0	21.3	705	804	755
02/12/99	15-18-2	TC3355	7.54	7.53	1439			0			0.0			0

Note: The empty cells and zero values are representative of the absence of a field measurement.

Appendix 23: Meteorological Summary – Edmonton City Centre Airport.

ENVIRONMENT CANADA

METEOROLOGICAL SUMMARY

EDMONTON CITY CENTRE AIRPORT SEPTEMBER 1998

Day	Max Temp C	Min Temp C	Mean Temp C	Degree Days Heat <18C	Degree Days Grow >5C	Degree Days Cool >18C	Max RH %	Min RH %	Precipitation Rain mm	Precipitation Snow cm	Precipitation Total mm	SOG cm	Mean Wind Speed Kmh	PEAK Dir	WIND Spd Kmh	GUST Hour LST	Sun-shine Hours
1	24.0	11.4	17.7	0.3	12.7	0.0	67	33	0.0	0.0	0.0	0	14.2	SSE	41	7	3.4
2	29.9	10.1	20.0	0.0	15.0	2.0	87	26	0.0	0.0	0.0	0	12.3	NNW	52	18	11.8
3	24.5	14.2	19.4	0.0	14.4	1.4	61	26	0.0	0.0	0.0	0	12.6				9.0
4	19.3	10.7	15.0	3.0	10.0	0.0	72	30	0.0	0.0	0.0	0	20.3	NW	63	4	12.7
5	20.5	10.2	15.4	2.6	10.4	0.0	62	33	0.0	0.0	0.0	0	10.3				7.7
6	24.5	11.2	17.9	0.1	12.9	0.0	50	31	0.0	0.0	0.0	0	20.1	SE	50	14	4.7
7	25.1	10.9	18.0	0.0	13.0	0.0	62	35	0.0	0.0	0.0	0	10.6	SE	39		11.1
8	19.8	13.2	16.5	1.5	11.5	0.0	68	43	TR	0.0	TR	0	20.1	NW	57	7	9.6
9	16.2	9.7	13.0	5.0	8.0	0.0	90	48	TR	0.0	TR	0	11.2				1.1
10	21.6	6.2	13.9	4.1	8.9	0.0	100	34	0.2	0.0	0.2	0	11.0	NW	44	2	12.4
11	24.4	7.7	16.1	1.9	11.1	0.0	77	32	0.0	0.0	0.0	0	9.1				9.7
12	24.7	7.5	16.1	1.9	11.1	0.0	83	26	0.0	0.0	0.0	0	9.7	SSW	37	15	7.5
13	18.6	8.6	13.6	4.4	8.6	0.0	80	28	0.0	0.0	0.0	0	14.5	NW	44	16	7.8
14	20.2	5.8	13.0	5.0	8.0	0.0	73	29	TR	0.0	TR	0	12.5	SE	44	14	3.0
15	18.6	4.5	11.6	6.4	6.6	0.0	83	32	0.0	0.0	0.0	0	9.7				10.1
16	22.2	4.7	13.5	4.5	8.5	0.0	70	31	0.0	0.0	0.0	0	11.0	N	37	19	11.6
17	15.9	4.7	10.3	7.7	5.3	0.0	87	35	TR	0.0	TR	0	12.0	ENE	37	14	6.4
18	11.0	7.6	9.3	8.7	4.3	0.0	100	43	14.6	0.0	14.6	0	13.7	ESE	33	5	.0
19	8.3	5.5	6.9	11.1	1.9	0.0	100	90	16.0	0.0	16.0	0	10.5				.0
20	18.1	3.4	10.8	7.2	5.8	0.0	100	54	0.0	0.0	0.0	0	9.4				9.8
21	20.9	5.8	13.4	4.6	8.4	0.0	94	37	0.0	0.0	0.0	0	9.2				11.4
22	19.8	5.9	12.9	5.1	7.9	0.0	90	46	TR	0.0	TR	0	9.0				4.7
23	18.5	4.5	11.5	6.5	6.5	0.0	97	51	3.0	0.0	3.0	0	9.5	N	44	18	2.5
24	12.1	7.4	9.8	8.2	4.8	0.0	93	65	2.2	0.0	2.2	0	12.9	NW	41	5	.5
25	10.2	4.9	7.6	10.4	2.6	0.0	98	81	8.0	0.0	8.0	0	13.8	NNW	44	17	.0
26	17.3	2.3	9.8	8.2	4.8	0.0	97	37	TR	0.0	TR	0	12.5	SW	32	13	11.0
27	19.2	9.2	14.2	3.8	9.2	0.0	77	44	0.4	0.0	0.4	0	10.5				6.0
28	14.9	6.2	10.6	7.4	5.6	0.0	93	60	0.0	0.0	0.0	0	11.5	N	37	21	6.0
29	11.4	2.5	7.0	11.0	2.0	0.0	95	41	0.0	0.0	0.0	0	9.8				9.6
30	14.8	1.4	8.1	9.9	3.1	0.0	82	54	0.0	0.0	0.0	0	19.9	S	44	10	10.9
Totals				150.5	242.9	3.4			44.4	0.0	44.4						212.0
Averages	18.9	7.3	13.1										12.5				
Normals	16.6	5.6	11.1	208.9	190.7	2.8			39.9	1.9	41.6		13.0	W	117		184.2

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ENVIRONMENT CANADA
MONTHLY METEOROLOGICAL SUMMARY
EDMONTON CITY CENTRE AIRPORT OCTOBER 1998

Day	Max Temp C	Min Temp C	Mean Temp C	Degree Days Heat <18C	Degree Days Grow >5C	Degree Days Cool >18C	Max RH %	Min RH %	Precipitation Rain mm	Precipitation Snow cm	Precipitation Total mm	SOG cm	Mean Wind Speed Kmh	PEAK Dir	WIND Spd Kmh	GUST Hour LST	Sun-shine Hours
1	18.0	4.9	11.5	6.5	6.5	0.0	82	39	0.0	0.0	0.0	0	22.3	SE	52	23	6.3
2	13.9	7.8	10.9	7.1	5.9	0.0	95	40	3.7	0.0	3.7	0	21.0	SE	44	1	3.3
3	14.9	4.5	9.7	8.3	4.7	0.0	97	52	0.5	0.0	0.5	0	11.2	E	35	17	8.7
4	14.1	-0.9	6.6	11.4	1.6	0.0	94	51	0.0	0.0	0.0	0	8.2				9.7
5	16.2	2.3	9.3	8.7	4.3	0.0	89	38	0.0	0.0	0.0	0	6.3				6.1
6	21.0	7.5	14.3	3.7	9.3	0.0	76	36	0.0	0.0	0.0	0	10.4				8.4
7	22.7	6.8	14.8	3.2	9.8	0.0	78	31	0.0	0.0	0.0	0	7.7				6.3
8	12.5	3.4	8.0	10.0	3.0	0.0	93	75	1.2	0.0	1.2	0	16.3	N	33	7	.0
9	3.5	0.4	2.0	16.0	0.0	0.0	98	92	2.8	13.0	15.8	0	15.5				.0
10	2.2	0.3	1.3	16.7	0.0	0.0	96	88	TR	TR	TR	0	8.8				.0
11	2.1	1.0	1.6	16.4	0.0	0.0	94	69	TR	0.0	TR	TR	7.5				.0
12	3.6	1.0	2.3	15.7	0.0	0.0	82	74	0.0	TR	TR	0	23.0	SE	52	13	.0
13	3.0	1.4	2.2	15.8	0.0	0.0	96	82	TR	0.0	TR	0	8.8	SE	33		.0
14	6.3	-0.4	3.0	15.0	0.0	0.0	100	80	TR	0.0	TR	0	4.3				.5
15	4.8	0.0	2.4	15.6	0.0	0.0	100	88	TR	0.0	TR	0	9.7				.0
16	5.2	2.0	3.6	14.4	0.0	0.0	99	82	0.8	0.0	0.8	0	11.4				.4
17	8.0	0.2	4.1	13.9	0.0	0.0	92	71	2.2	0.0	2.2	0	16.3	NW	52	19	1.5
18	8.6	0.6	4.6	13.4	0.0	0.0	76	38	0.0	0.0	0.0	0	18.0	NW	41	13	8.4
19	13.2	4.8	9.0	9.0	4.0	0.0	67	45	0.0	0.0	0.0	0	13.8	WNW	35	13	5.8
20	17.5	3.0	10.3	7.7	5.3	0.0	79	40	0.0	0.0	0.0	0	10.2				7.5
21	21.7	3.1	12.4	5.6	7.4	0.0	74	32	0.0	0.0	0.0	0	8.0				9.3
22	19.1	1.1	10.1	7.9	5.1	0.0	93	41	0.0	0.0	0.0	0	3.5				9.4
23	19.2	0.2	9.7	8.3	4.7	0.0	95	39	0.0	0.0	0.0	0	3.8				9.3
24	16.3	-1.3	7.5	10.5	2.5	0.0	90	42	0.0	0.0	0.0	0	8.1				9.3
25	12.8	-0.2	6.3	11.7	1.3	0.0	95	61	0.0	0.0	0.0	0	11.2				4.8
26	15.2	2.4	8.8	9.2	3.8	0.0	78	35	0.0	0.0	0.0	0	10.1	W	35	13	9.0
27	17.5	1.1	9.3	8.7	4.3	0.0	87	44	0.0	0.0	0.0	0	17.9	SSE	56	21	7.4
28	12.9	0.8	6.9	11.1	1.9	0.0	80	35	0.2	TR	0.2	0	17.2	NW	65	10	1.2
29	8.6	-3.2	2.7	15.3	0.0	0.0	88	33	0.0	TR	TR	0	9.1	N	37	21	7.6
30	4.3	-4.2	0.1	17.9	0.0	0.0	82	49	0.0	0.0	0.0	0	10.9				7.8
31	6.6	-1.3	2.7	15.3	0.0	0.0	75	52	0.0	0.0	0.0	0	17.0	SE	33	3	5.6
Totals				350.0	85.4	0.0			11.4	13.0	24.4						153.6
Averages	11.8	1.6	6.7										11.8				
Normals	11.3	0.6	5.9	374.2	77.1	0.1			10.0	7.4	17.3		13.0	NW	113		164.5

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ENVIRONMENT CANADA
MONTHLY METEOROLOGICAL SUMMARY
EDMONTON CITY CENTRE AIRPORT NOVEMBER 1998

Day	Max Temp C	Min Temp C	Mean Temp C	Degree Days Heat <18C	Grow >5C	Cool >18C	Max RH %	Min RH %	Precipitation Rain mm	Snow cm	Total mm	SOG cm	Mean Wind Speed Kmh	PEAK Dir	WIND Spd Kmh	GUST Hour LST	Sun-shine Hours
1	1.3	-2.4	-0.6	18.6	0.0	0.0	96	78	0.6	TR	0.6	0	6.9				.0
2	1.1	-0.4	0.4	17.6	0.0	0.0	98	92	TR	6.8	6.4	5	7.3				.0
3	2.6	0.5	1.6	16.4	0.0	0.0	98	90	TR	0.4	0.4	TR	3.8				.0
4	4.3	2.2	3.3	14.7	0.0	0.0	91	72	0.0	0.0	0.0	0	12.7				.0
5	3.4	1.3	2.4	15.6	0.0	0.0	92	85	TR	TR	TR	0	15.6				.0
6	1.3	-3.9	-1.3	19.3	0.0	0.0	87	76	0.0	TR	TR	0	15.9				.0
7	-2.1	-6.9	-4.5	22.5	0.0	0.0	82	68	0.0	0.0	0.0	0	13.8				.1
8	-0.2	-3.0	-1.6	19.6	0.0	0.0	86	70	0.0	TR	TR	0	3.9				.0
9	-1.1	-5.6	-3.4	21.4	0.0	0.0	87	57	0.0	TR	TR	0	10.8				.0
10	-3.9	-7.8	-5.9	23.9	0.0	0.0	83	58	0.0	0.2	0.2	0	17.4	NW	44	7	.7
11	-4.9	-10.5	-7.7	25.7	0.0	0.0	87	66	0.0	1.8	1.4	2	11.9				.0
12	2.7	-5.5	-1.4	19.4	0.0	0.0	79	64	0.0	0.0	0.0	2	10.7				1.8
13	1.3	-7.0	-2.9	20.9	0.0	0.0	95	72	0.0	5.4	4.4	2	11.5				.7
14	-3.3	-9.2	-6.3	24.3	0.0	0.0	94	75	0.0	0.0	0.0	5	9.8				6.2
15	-7.9	-11.6	-9.8	27.8	0.0	0.0	87	80	0.0	11.0	9.2	7	18.1	E	32		.0
16	-9.7	-11.8	-10.8	28.8	0.0	0.0	86	77	0.0	5.4	3.8	14	8.5				.2
17	-9.4	-13.2	-11.3	29.3	0.0	0.0	89	79	0.0	TR	TR	16	17.8	S	35	9	3.5
18	-6.2	-10.4	-8.3	26.3	0.0	0.0	95	87	0.0	0.6	0.4	16	8.6				.0
19	-4.9	-13.3	-9.1	27.1	0.0	0.0	94	75	0.0	0.0	0.0	16	6.6				6.1
20	1.3	-12.1	-5.4	23.4	0.0	0.0	91	62	0.0	0.0	0.0	10	9.6	SSE	41	15	1.8
21	4.4	-8.6	-2.1	20.1	0.0	0.0	93	73	0.0	0.0	0.0	9	7.8	NW	48	13	4.3
22	2.3	-9.2	-3.5	21.5	0.0	0.0	94	60	0.0	0.0	0.0	9	7.1				5.9
23	1.4	-8.5	-3.6	21.6	0.0	0.0	77	53	0.0	0.0	0.0	9	7.2				5.0
24	0.1	-9.3	-4.6	22.6	0.0	0.0	95	70	0.0	0.0	0.0	9	7.5				3.2
25	2.9	-9.1	-3.1	21.1	0.0	0.0	89	55	0.0	0.0	0.0	9	8.1				2.4
26	3.2	-3.0	0.1	17.9	0.0	0.0	87	69	0.2	0.2	0.4	9	9.7	W	32	12	.0
27	2.9	-5.2	-1.2	19.2	0.0	0.0	87	50	0.0	0.0	0.0	8	7.6				7.0
28	-0.4	-11.2	-5.8	23.8	0.0	0.0	93	59	0.0	0.0	0.0	8	6.4				5.3
29	-4.1	-14.9	-9.5	27.5	0.0	0.0	98	70	0.0	0.0	0.0	8	4.8				6.1
30	-4.1	-15.8	-10.0	28.0	0.0	0.0	92	66	0.0	0.0	0.0	8	6.3				6.4
Totals				665.9	0.0	0.0			0.8	31.9	27.2						66.7
Averages	-.9	-7.5	-4.2										9.8				
Normals	-0.1	-8.4	-4.2	668.1	3.6	0.0			2.2	16.3	16.1		12.0	NW	100		101.1

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STATION NAME EDMONTON MUN (YXD)
Environment Canada
January, 1999.

Prairie & Northern Region

DATE	TEMPERATURE TEMPERATURE Maximum C	Minimum C	Mean C	DEGREE-DAYS DEGRES-JOURS Heating base 18	Growing base 5	Cooling base 18	REL HUMIDITY HUMIDITE REL %	%	PRECIPITATION PRECIPITATIONS Rain - fall mm	Snow - fall cm	Total Precip mm	cm
1	-16.3	-22.7	-19.5	37.5	0	0	74	62	0	1.4	0.7	14
2	-15.5	-24.5	-20.0	38.0	0	0	77	67	0	TR	TR	14
3	-8.2	-19.8	-14.0	32.0	0	0	88	68	0	0.8	0.8	16
4	1.3	-8.3	-3.5	21.5	0	0	98	83	0.2	8.8	8	19
5	-6.1	-20.1	-13.1	31.1	0	0	97	86	0	7	5.2	22
6	-19.7	-27.3	-23.5	41.5	0	0	99	65	0	TR	TR	24
7	-20.3	-26.6	-23.5	41.5	0	0	76	64	0	0.4	0.4	24
8	-14.2	-29.2	-21.7	39.7	0	0	74	23	0	4	1.8	25
9	-15.3	-19.7	-17.5	35.5	0	0	78	63	0	5	3.6	26
10	-16.4	-18.8	-17.6	35.6	0	0	77	69	0	5	2.6	30
11	-17.9	-23.8	-20.9	38.9	0	0	74	51	0	12	7.8	32
12	-2.8	-24.7	-13.8	31.8	0	0	91	69	0	3.6	2.2	34
13	-0.7	-6.8	-3.8	21.8	0	0	82	61	0	0	0	37
14	4.8	-3.9	0.5	17.5	0	0	89	59	TR	0	TR	36
15	4.4	-3.0	0.7	17.3	0	0	89	47	TR	TR	TR	34
16	-2.4	-11.1	-6.8	24.8	0	0	81	59	0	0	0	33
17	-5.1	-14.4	-9.8	27.8	0	0	94	65	0	0	0	33
18	-8.5	-15.5	-12.0	30.0	0	0	95	85	0	4.6	3.4	33
19	-9.3	-13.4	-11.4	29.4	0	0	97	82	0	0.4	0.2	33
20	-9.3	-18.5	-13.9	31.9	0	0	95	82	0	0.8	0.6	33
21	-12.8	-15.1	-14.0	32.0	0	0	98	85	0	3.6	1.6	34
22	-13.2	-17.3	-15.3	33.3	0	0	90	86	0	4	3.6	35
23	-17.3	-25.0	-21.2	39.2	0	0	90	62	0	0.6	0.4	42
24	-2.3	-26.2	-14.3	32.3	0	0	73	40	0	0	0	43
25	-1.1	-11.8	-6.5	24.5	0	0	76	56	0	0	0	42
26	-5.7	-10.1	-7.9	25.9	0	0	96	62	0	3.6	2.4	42
27	-6.6	-17.7	-12.2	30.2	0	0	98	69	0	0	0	43
28	-1.4	-13.0	-7.2	25.2	0	0	83	55	0	0	0	41
29	5.4	-10.0	-2.3	20.3	0	0	83	54	0	0	0	41
30	-7.3	-14.9	-11.1	29.1	0	0	92	72	0	TR	TR	40
31	-9.4	-14.6	-12.0	30.0	0	0	94	84	0	0.2	TR	40
TOTL	-249.2	-527.8		947.1	0.0	0.0			0.2	65.8	45.3	
MEAN	-8.0	-17.0	-12.5				87	66				
NORM	-8.2	-17.0	-12.5	948.0	0.2	0.0			2.0	25.6	23.3	

NOTE: The above data data has been fully Quality Controlled

STATION NAME : EDMONTON MUN (YXD)
Environment Canada
February, 1999.

Prairie & Northern Region

DATE	TEMPERATURE TEMPERATURE			DEGREE-DAYS DEGRES-JOURS			REL HUMIDITY HUMIDITE REL		PRECIPITATION PRECIPITATIONS			
	Maximum	Minimum	Mean	Heating	Growing	Cooling			Rain - fall	Snow - fall	Total Precip	
	C	C	C	base 18	base 5	base 18	%	%	mm	cm	mm	cm
1	-3.3	-12.9	-8.1	26.1	0	0	89	49	0	0	0	40
2	-4.3	-9.7	-7.0	25.0	0	0	91	67	0	2.8	1.4	40
3	-9.7	-18.3	-14.0	32.0	0	0	89	69	0	4.8	3.2	40
4	-13.0	-18.4	-15.7	33.7	0	0	94	68	0	0.4	0.2	39
5	-7.8	-19.8	-13.8	31.8	0	0	95	74	0	0	0	39
6	1.1	-12.5	-5.7	23.7	0	0	91	50	0	0	0	39
7	-3.9	-12.2	-8.1	26.1	0	0	98	76	0	0	0	39
8	-0.1	-14.3	-7.2	25.2	0	0	95	56	0	0	0	39
9	-2.8	-14.9	-8.9	26.9	0	0	91	59	0	0	0	39
10	-11.3	-18.2	-14.8	32.8	0	0	97	88	0	TR	TR	39
11	-3.2	-19.9	-11.6	29.6	0	0	85	50	0	0	0	39
12	6.0	-11.4	-2.7	20.7	0	0	73	44	0	0	0	39
13	6.6	-8.1	-0.8	18.8	0	0	83	42	0	0	0	39
14	2.6	-8.4	-2.9	20.9	0	0	89	52	0	0	0	39
15	0.6	-11.8	-5.6	23.6	0	0	91	47	0	0	0	39
16	-5.0	-11.3	-8.2	26.2	0	0	95	84	0	TR	TR	39
17	-4.2	-6.1	-5.2	23.2	0	0	93	85	0	TR	TR	39
18	-1.7	-10.5	-6.1	24.1	0	0	93	66	0	0	0	39
19	-6.2	-10.9	-8.6	26.6	0	0	92	77	0	TR	TR	39
20	1.6	-12.7	-5.6	23.6	0	0	92	52	0	0	0	39
21	0.3	-6.0	-2.9	20.9	0	0	77	56	0	0	0	39
22	-0.1	-7.3	-3.7	21.7	0	0	93	63	0	0	0	39
23	4.1	-5.8	-0.9	18.9	0	0	84	32	0	0	0	38
24	1.3	-8.3	-3.5	21.5	0	0	84	38	0	0	0	38
25	5.3	-6.5	-0.6	18.6	0	0	86	57	0	0	0	38
26	4.7	-6.7	-1.0	19.0	0	0	92	52	0	0	0	37
27	2.5	-5.6	-1.6	19.6	0	0	95	47	0	0	0	37
28	1.6	-11.3	-4.9	22.9	0	0	94	68	0	0	0	37
TOTL	-38.3	-280.0		683.7	0.0	0.0			0.0	8.0	4.8	
MEAN	-1.4	-11.4	-6.4				90	60				
NORM	-4.2	-13.7	-8.9	761.0	0.3	0.0			0.8	19.6	16.8	

NOTE 1. Climatological Day: 01 01 LST - 01 00 LST 1. Journee Climatologique: 23 01 LST - 23 00 LST
2. Normal 1961 - 1990 2. Normale 1961 - 1990
3. TR = Trace 3. TR = Trace
4. No entry = Missing 4. Pas de Valeur = Manquant

NOTE: The above data data has been fully Quality Controlled.

Appendix 24: Volumetric Concentration of Target VOC Compounds.

Legend for Volatile Organic Compounds in Table:

1. Chloroform
2. 1,1,1-trichloroethane
3. Carbon tetrachloride
4. Benzene
5. Trichloroethylene
6. Toluene
7. Tetrachloroethylene
8. Chlorobenzene
9. Ethylbenzene
10. (m+p) Xylene
11. o-Xylene
12. Napthalene
13. 1,3,5-trimethylbenzene
14. 1,4-dichlorobenzene
15. Styrene

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
KB6088	53	20	17	141	BDL	203	17	3	29	74	36	11	15	BDL	BDL
KB6088DUP	63	27	25	190	BDL	284	BDL	6	29	115	52	12	22	4	BDL
KB6091	66	17	16	110	BDL	205	28	5	20	61	26	9	12	BDL	BDL
KB6094	111	23	24	150	BDL	266	25	4	32	93	43	8	19	BDL	BDL
KB6097	87	13	15	152	BDL	143	BDL	4	15	43	19	8	14	BDL	BDL
KB6100	126	25	22	130	BDL	308	18	5	35	89	41	9	21	BDL	BDL
KB6101	65	BDL	15	118	BDL	186	8	2	20	56	32	7	13	BDL	BDL
KB6102	89	9	BDL	92	BDL	139	BDL	3	10	24	12	7	8	BDL	BDL
KB6103	109	28	14	159	BDL	329	13	5	41	177	78	10	25	BDL	BDL
KB6104	55	BDL	17	101	BDL	148	BDL	2	11	35	16	9	6	BDL	BDL
KB6105	54	28	17	105	BDL	178	BDL	4	10	36	18	10	10	BDL	BDL
KU7937	47	7	BDL	104	BDL	224	25	7	14	36	19	10	8	7	BDL
KU9260	95	22	15	179	BDL	437	23	8	38	107	56	11	25	45	9
TC0000	48	26	17	142	9	302	21	BDL	36	103	42	9	21	3	BDL
TC3418	86	314	BDL	107	BDL	278	10	2	25	58	27	9	14	BDL	BDL
TC3423	240	39	21	207	BDL	325	22	4	40	110	48	8	30	9	BDL
TC3426	154	297	BDL	114	BDL	290	12	2	24	76	35	8	19	9	BDL
TC3428	148	361	15	138	BDL	516	39	3	48	105	47	10	24	9	BDL
TC3429	73	22	18	149	BDL	277	24	4	23	64	35	8	20	BDL	BDL
TC3430	88	13	18	135	BDL	176	BDL	2	21	76	31	7	14	BDL	BDL
TC3442	118	34	18	192	BDL	336	26	4	32	119	54	11	25	4	BDL
JA8875		22	25	123	25	302	27	7	22	93	30	10	7	BDL	BDL
JA9613	18	15	18	BDL	BDL	133	16	7	19	90	26	BDL	6	BDL	BDL
JA9617	42	151	22	BDL	24	513	81	11	95	317	124	15	79	72	34
JA9622	15	25	26	BDL	17	161	BDL	9	21	75	30	BDL	4	3	BDL
JA9625	36	17	29	BDL	BDL	118	BDL	6	11	61	15	BDL	BDL	BDL	BDL
JA9641	BDL	28	29	BDL	20	306	18	10	34	116	44	13	13	BDL	BDL
JA9662	10	22	26	BDL	21	247	20	11	25	84	32	BDL	7	BDL	17
JA9663	19	26	29	BDL	18	189	20	9	29	106	33	BDL	9	BDL	45
JA9665	30	27	29	BDL	25	382	30	11	37	122	47	12	14	BDL	BDL
JA9679	66	15	20	BDL	17	268	BDL	8	36	130	51	12	17	BDL	24
JA9682	31	27	33	BDL	22	274	23	10	18	59	21	12	BDL	5	BDL
JA9688	63	183	27	214	19	741	33	11	70	222	74	15	18	7	86

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
JA9693															
JA9694	188	51	40	BDL	25	392	27	10	49	180	56	17	22	5	17
JA9695															
JA9698															
JA9700	27	26	22	BDL	25	256	BDL	8	22	84	31	10	10	5	BDL
JA9707	29	17	16	150	38	459	BDL	6	55	166	85	10	21	BDL	23
JA9722	332	91	29	BDL	31	620	211	11	93	328	126	18	161	15	63
JA9723	52	399	31	BDL	26	797	380	9	133	465	106	16	33	8	BDL
JA9728	BDL	23	34	BDL	23	565	31	12	55	233	86	17	23	16	30
JA9732	19	25	29	BDL	21	189	19	9	19	86	30	BDL	7	BDL	BDL
JA9749	95	33	34	40	24	653	394	10	111	407	132	16	30	19	42
JA9763	65	42	25	BDL	23	489	53	10	65	265	93	14	BDL	7	BDL
JA9773	86	37	23	BDL	9	315	BDL	9	42	155	56	18	18	9	24
JA9775	BDL	18	30	BDL	26	404	70	10	19	111	37	13	11	5	BDL
JA9784	153	21	34	BDL	15	395	32	10	46	166	57	16	15	5	28
JA9786	62	67	26	BDL	24	347	49	9	33	115	37	BDL	14	17	19
JA9787	75	20	19	BDL	16	311	BDL	6	97	391	142	99	45	BDL	28
JA9793	76	171	47	BDL	26	1550	41	8	125	469	152	BDL	62	83	30
JA9794	13	33	28	BDL	19	315	28	8	36	142	55	7	12	BDL	51
JA9800	19	14	22	140	17	274	BDL	5	14	66	27	9	8	BDL	BDL
JA9801	28	17	26	82	19	1373	138	9	182	717	252	21	76	6	53
JA9807	16	13	BDL	96	BDL	107	BDL	3	6	39	17	7	BDL	BDL	BDL
JA9807DUP	17	17	19	141	BDL	172	10	6	19	58	23	8	BDL	BDL	BDL
JA9809	14	124	22	BDL	20	1165	43	8	164	673	217	16	43	12	11
JA9810	51	14	16	BDL	24	315	16	8	69	244	116	BDL	208	4	BDL
JA9812	24	19	28	BDL	20	224	22	7	18	74	26	12	6	BDL	BDL
JA9815	19	35	39	BDL	29	307	26	13	35	121	39	10	6	BDL	BDL
JA9818	17	35	27	BDL	23	295	BDL	10	32	136	45	15	11	BDL	26
JA9840	13	90	21	BDL	23	1049	41	8	158	603	201	15	37	10	8
JA9849	11	17	19	BDL	10	191	BDL	7	26	89	33	10	6	4	7
JA9860	76	103	31	BDL	31	874	32	10	147	558	205	16	42	8	BDL
JA9867	42	16	20	BDL	BDL	343	BDL	6	43	136	35	14	15	6	280
JA9868	20	11	19	97	BDL	126	BDL	4	2	30	15	6	BDL	BDL	BDL

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
JC7774	113	248	33	303	31	957	69	9	98	373	124	28	67	17	16
JC7805	75	62	24	461	17	486	26	6	27	110	43	22	15	BDL	4
JC7861															
JC7873	45	26	28	330	BDL	133	BDL	6	12	69	28	17	9	BDL	BDL
JC7897	51	20	27	327	BDL	161	BDL	6	28	110	45	15	14	BDL	BDL
JC7901	131	1039	21	BDL	29	560	26	3	59	197	74	10	22	14	60
JC7924	30	17	15	232	BDL	151	BDL	6	22	51	29	7	11	BDL	BDL
JC7937	45	25	26	200	15	439	26	5	136	518	207	12	104	2	3
JC7937DUP	41	41	31	310	BDL	685	41	6	195	792	315	17	145	4	8
JC7940	26	12	17	BDL	BDL	95	BDL	5	17	74	34	22	11	BDL	BDL
JC7947	67	94	30	471	20	526	BDL	6	85	282	92	24	29	87	19
JD2432	81	21	25	182	17	380	74	8	79	304	93	BDL	20	6	32
JD2488	36	16	25	118	BDL	94	BDL	8	17	57	21	12	63	7	BDL
JD2500	60	212	14	487	16	1452	131	6	131	467	168	13	36	BDL	22
JD2508	14	11	19	63	BDL	195	16	6	19	94	42	8	10	3	BDL
JD2541	49	19	26	365	15	268	40	5	50	176	69	14	16	BDL	BDL
JD2552	35	18	28	115	18	136	15	7	21	82	25	7	BDL	11	BDL
JD2562	103	24	25	125	43	432	15	7	28	104	29	BDL	28	BDL	BDL
JD2581	79	26	35	470	BDL	603	BDL	7	85	306	107	18	28	BDL	15
JD2582	325	51	31	206	BDL	1558	186	BDL	4294	15206	5257	67	366	14	196
JD2591	87	448	43	637	94	1394	85	7	319	1274	384	22	74	BDL	18
JD2604	106	36	31	174	19	280	38	10	46	139	51	19	12	BDL	15
JD2608	55	73	18	224	BDL	392	25	8	156	608	161	29	43	7	38
JD2609	47	20	30	447	15	330	60	7	61	233	83	18	21	BDL	BDL
JD2610	317	43	29	262	19	1504	187	8	4615	15804	5551	85	3873	11	208
JD2621	22	14	21	92	BDL	116	10	5	14	62	24	7	BDL	4	BDL
JD2645	44	17	19	136	21	173	24	9	23	80	22	BDL	6	BDL	BDL
JP1699	39	32	23	100	47	250	11	3	31	126	39	BDL	12	BDL	BDL
JP1782	40	39	35	174	49	352	BDL	4	32	123	56	12	12	BDL	BDL
JP1799	30	36	31	103	43	385	22	BDL	20	52	28	10	21	BDL	BDL
JP1831	37	67	21	256	28	873	26	3	119	496	167	8	33	BDL	BDL
JP1850	46	66	15	72	30	493	31	3	27	117	51	8	23	7	BDL
JP1851	50	37	40	172	41	259	27	BDL	42	143	62	11	15	5	BDL

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
JP1859	37	46	31	67	45	599	14	3	33	150	61	8	10	BDL	BDL
JP1864	21	9	BDL	73	17	158	BDL	BDL	6	25	12	6	6	BDL	BDL
JP1875	163	69	41	258	77	867	82	6	72	278	95	10	16	57	BDL
JP1904	36	29	27	87	44	292	22	3	38	136	41	11	10	BDL	BDL
JP1924	31	24	21	91	36	208	BDL	5	34	137	38	3	11	4	BDL
JP2123	29	35	BDL	BDL	34	524	BDL	3	36	132	64	9	11	BDL	BDL
JP2133	24	25	21	BDL	31	2596	BDL	3	24	88	26	10	13	BDL	BDL
JP2169	41	26	32	58	46	454	BDL	4	39	149	57	16	14	BDL	BDL
JP2177	46	29	25	160	64	619	153	8	57	190	69	21	38	21	BDL
JP2199	30	18	5	82	30	200	BDL	2	29	102	34	BDL	10	BDL	BDL
JP2211	23	21	28	BDL	22	143	BDL	3	15	53	27	BDL	BDL	BDL	BDL
JP2231	54	18	18	65	17	189	BDL	BDL	11	42	22	9	7	BDL	BDL
JP2233	44	22	19	93	32	186	14	3	32	113	34	BDL	8	3	BDL
JP2251	20	13	BDL	92	18	162	BDL	5	14	57	29	14	9	4	BDL
JP2274	67	27	19	86	28	364	298	3	34	107	34	BDL	9	BDL	BDL
JP2280	77	443	18	69	34	274	19	BDL	67	219	66	16	17	BDL	26
JP2280DUP	62	471	17	112	40	328	25	5	87	260	74	13	19	BDL	29
JP2281	20	17	23	57	BDL	208	14	3	15	44	21	4	8	BDL	BDL
JP2459	31	33	13	BDL	23	477	16	3	44	140	67	10	9	BDL	BDL
JP2496	30	18	19	BDL	27	159	BDL	BDL	12	55	24	9	9	BDL	BDL
JP2496DUP	42	36	41	159	34	568	BDL	6	37	130	44	19	14	BDL	BDL
JP2497	42	22	12	63	23	138	BDL	4	26	90	30	9	6	BDL	BDL
JP2522	161	50	23	565	36	1062	20	BDL	516	1999	561	10	134	4	37
JP2530	43	26	22	107	61	352	BDL	BDL	32	126	43	16	11	BDL	BDL
JP2620	68	98	19	69	31	363	34	2	46	169	66	7	16	BDL	BDL
JP2656															
JP2668	57	22	30	480	44	520	20	BDL	117	388	146	17	40	BDL	BDL
JP2668DUP	53	29	36	718	54	724	42	8	149	512	179	22	51	BDL	BDL
KB9938	55	24	31	431	BDL	259	38	11	42	132	54	22	18	BDL	BDL
KT9957	BDL	43	27	BDL	BDL	501	49	5	74	256	109	16	37	11	25
KT9958	BDL	32	22	BDL	28	798	35	4	59	217	81	27	37	12	BDL
KT9960	37	39	38	201	BDL	261	BDL	4	10	47	36	11	18	9	BDL
KT9960DUP	45	44	27	259	BDL	362	BDL	4	15	78	37	17	23	9	BDL

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
KT9961	BDL	29	26	BDL	14	550	42	6	55	202	76	15	28	9	BDL
KT9962	BDL	266	25	BDL	26	2017	175	5	316	1212	423	22	146	11	29
KT9988	34	43	39	BDL	29	818	62	4	91	357	130	21	52	15	31
KT9989	BDL	171	28	BDL	36	1045	71	6	83	295	110	23	41	14	28
KT9990															
KT9991	BDL	37	27	BDL	15	1323	315	6	90	306	114	17	38	12	37
KU6353	60	29	40	213	BDL	437	64	17	30	82	35	20	16	9	BDL
KU6537	278	581	72	379	24	476	24	11	66	213	69	14	19	363	36
KU7940	133	54	31	584	BDL	1390	38	13	235	808	269	21	59	22	20
KU9264	65	184	23	732	BDL	1833	84	BDL	277	932	290	17	74	8	BDL
TC0043	BDL	22	27	BDL	15	653	31	5	84	311	114	17	40	BDL	BDL
TC0046	66	60	31	BDL	7	1119	145	5	109	454	152	17	42	5	26
TC0047	208	58	BDL	BDL	BDL	618	39	6	72	233	72	32	26	71	20
TC0050	BDL	32	31	BDL	23	669	34	4	59	208	74	13	33	2	8
TC0051	BDL	40	36	BDL	11	615	35	5	71	266	100	25	38	8	BDL
TC0053	8	86	27	BDL	21	1248	41	5	89	296	93	18	45	6	32
TC0079	BDL	32	27	BDL	21	823	40	4	68	254	99	14	36	BDL	BDL
TC0080	BDL	290	BDL	BDL	25	960	47	5	77	276	109	20	37	6	15
TC0081	137	134	BDL	BDL	9	613	1122	5	90	311	93	19	32	12	9
TC0083	BDL	40	35	BDL	22	743	40	7	52	203	76	19	33	2	BDL
TC3433	60	51	25	667	27	829	86	14	141	499	176	27	68	114	26
TC3436	102	43	40	483	24	1889	39	5	304	1188	392	21	37	15	18
TC3439	271	566	71	319	30	485	25	5	65	241	88	12	26	444	50
TK5855	44	45	25	253	33	691	10	12	847	358	94	11	38	10	60
TK5860	41	20	27	249	BDL	538	61	12	61	258	96	18	30	7	15
TK5873	125	22	28	338	41	885	70	15	151	531	235	24	307	14	30
TK5882	116	86	32	415	39	949	45	15	125	479	173	20	44	14	48
TK5886	350	668	88	383	54	673	23	16	84	274	87	17	20	446	66
TK5886DUP	298	612	79	394	44	618	21	13	67	241	81	11	18	384	60
TK5887	44	12	18	358	26	252	BDL	11	20	72	26	15	8	7	BDL
TK5905	44	20	30	277	BDL	560	BDL	13	98	354	135	17	30	9	BDL
TK5919	36	20	29	312	41	771	33	15	112	401	158	16	40	14	BDL
TK5987	43	19	30	280	38	712	57	16	80	310	107	15	37	BDL	16

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TK5999	103	4628	BDL	310	41	1094	1271	17	119	379	161	29	49	19	17
TK6026	370	67	44	242	BDL	2178	223	16	5198	18228	6489	95	4395	13	229
TK6338	43	26	49	182	BDL	556	41	16	40	124	57	14	12	BDL	BDL
TK6427	65	132	37	210	BDL	512	31	16	55	203	84	22	30	51	25
TK6427DUP	49	154	26	228	BDL	630	40	16	75	232	88	25	42	58	39
TU2794	46	19	42	BDL	BDL	354	30	7	27	77	32	12	BDL	16	BDL
JP1730	98	43	22	188	30	829	26	4	182	674	178	27	39	70	BDL
JP1756	167	80	23	168	39	513	78	6	60	236	89	12	48	4	15
JP1889	44	19	26	146	31	232	BDL	BDL	37	126	47	BDL	16	BDL	BDL
JP1901	48	28	20	117	45	318	BDL	4	30	125	48	24	14	BDL	BDL
KT9891	104	36	23	92	51	2348	BDL	6	41	131	65	13	69	BDL	32
KT9894	31	28	24	85	BDL	284	BDL	BDL	18	68	34	9	23	BDL	BDL
KT9895	41	24	21	97	BDL	323	32	4	21	62	31	9	21	BDL	BDL
KT9895DUP	23	29	25	96	BDL	323	33	4	18	54	29	3	16	BDL	BDL
KT9896	265	21	28	180	BDL	509	254	4	58	229	99	22	44	11	47
KT9899	89	52	21	102	23	565	37	4	38	122	66	9	30	BDL	7
KT9900	151	109	35	100	14	499	34	3	41	134	60	19	67	BDL	45
KT9900DUP	159	130	40	174	BDL	610	36	BDL	42	151	71	27	65	BDL	50
KT9901	32	24	15	118	BDL	368	27	4	37	140	61	19	24	BDL	BDL
KT9902	10	43	20	190	24	775	43	6	65	261	118	27	42	BDL	BDL
KT9979	25	22	20	66	BDL	257	20	3	16	47	17	6	12	3	BDL
KT9980	50	26	BDL	85	BDL	271	57	3	27	98	56	12	23	BDL	29
KT9981	30	22	19	62	15	277	26	4	17	59	22	14	14	BDL	BDL
KT9981DUP	15	28	24	66	BDL	391	33	5	17	64	25	34	16	4	BDL
KT9982	38	113	BDL	118	BDL	404	BDL	3	33	110	30	19	16	4	30
KT9983	25	15	19	74	BDL	214	27	3	20	70	32	29	13	BDL	BDL
KT9985	26	22	18	65	15	187	20	3	12	47	15	10	11	BDL	BDL
KT9986	26	26	21	79	BDL	218	BDL	BDL	21	63	21	21	14	BDL	BDL
KT9987	55	94	17	87	22	861	54	4	42	131	68	19	34	16	31
TC0200	46	67	24	85	BDL	411	118	3	29	109	47	22	22	BDL	22
TC0201	38	21	17	86	17	357	27	3	25	62	28	18	17	BDL	BDL
TC0202	218	27	43	112	16	628	39	4	56	191	84	21	41	BDL	63
TC0203	33	26	19	74	BDL	532	33	4	20	64	29	19	19	BDL	BDL

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TC0204	42	32	20	122	20	532	25	4	51	215	93	15	36	BDL	BDL
TC0205	54	22	24	233	BDL	725	37	6	70	223	86	25	35	BDL	136
TC0206	32	19	18	88	14	308	17	4	22	77	42	18	20	BDL	BDL
TC0207	78	567	19	242	25	853	150	4	57	218	95	23	33	6	29
TC0208	90	31	20	158	BDL	645	102	4	59	256	98	21	39	BDL	22
TC0209	29	22	20	122	21	494	28	5	46	199	81	18	30	BDL	BDL
TC0209DUP	26	37	29	198	23	611	29	5	56	209	84	20	33	BDL	BDL
TC3348	24	41	38	159	BDL	1888	42	6	97	317	84	8	31	BDL	BDL
TC3349	32	14	20	48	BDL	185	BDL	3	18	65	22	12	11	BDL	BDL
TC3350	37	21	22	99	BDL	343	33	4	59	205	65	BDL	26	6	BDL
TC3351	47	42	21	98	BDL	381	25	4	62	237	69	BDL	23	38	26
TC3351DUP	52	57	18	162	BDL	527	36	5	90	299	83	36	29	41	24
TC3352	64	47	27	170	BDL	552	50	4	83	322	87	37	34	51	40
TC3354	38	28	25	125	BDL	357	41	4	34	140	39	23	24	BDL	BDL
TC3355	34	18	15	62	BDL	243	5	2	20	63	24	9	10	BDL	BDL
TC3356	36	25	19	78	BDL	298	BDL	BDL	34	118	30	20	18	BDL	BDL
TC3357	60	28	20	92	BDL	351	18	3	40	122	48	16	14	4	15
TC3373	29	24	20	54	BDL	193	BDL	3	11	34	25	9	11	BDL	BDL
TC3374	29	16	14	68	BDL	214	10	BDL	29	112	43	7	16	BDL	BDL
TC3375	53	68	27	102	BDL	428	134	6	71	225	92	17	31	10	34
TC3376	29	23	18	BDL	BDL	192	BDL	4	13	35	16	6	5	BDL	BDL
TC3377	42	33	15	102	BDL	331	29	BDL	56	211	280	BDL	664	BDL	19
TC3378	35	26	19	68	BDL	592	33	3	44	160	63	11	22	BDL	23
TC3379	34	18	12	43	9	286	16	2	10	58	23	11	13	BDL	BDL
TC3380	21	20	16	61	BDL	131	BDL	3	14	36	15	BDL	7	BDL	BDL
TC3380DUP	17	25	19	79	BDL	156	11	3	10	35	17	9	9	BDL	BDL
TC3381	43	64	16	91	BDL	200	41	3	49	217	79	11	30	9	17
TC3382	23	17	18	50	BDL	280	19	3	25	55	21	BDL	9	BDL	BDL
TC3383	38	14	16	59	BDL	194	BDL	2	24	64	22	12	13	BDL	BDL
TC3384	43	42	45	182	124	561	19	7	69	230	94	26	44	BDL	57
TC3385	68	28	21	BDL	BDL	347	33	BDL	20	BDL	62	BDL	15	6	67
TC3386	27	21	15	80	BDL	280	24	3	19	74	34	12	161	3	BDL
TC3387	76	43	43	91	BDL	650	25	9	45	152	65	22	32	BDL	BDL

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TC3388	37	19	21	74	BDL	266	BDL	5	28	80	43	10	20	BDL	BDL
TC3391	97	239	30	385	BDL	1257	89	4	108	400	142	8	33	BDL	37
TC3396	60	20	19	BDL	8	180	26	3	14	52	22	9	15	BDL	11
TC3397	46	30	29	BDL	13	253	21	5	30	74	31	9	18	BDL	BDL
TC3398	89	29	27	96	BDL	438	12	6	49	171	63	7	30	6	16
TC3460	42	27	32	132	BDL	365	23	6	32	100	36	BDL	21	BDL	BDL
TC3461	35	20	23	80	BDL	298	14	5	28	71	43	13	20	BDL	BDL
TC3464	142	83	18	114	BDL	442	27	3	46	112	49	AD SIGN	23	AD SIGN	30
TC3466	23	19	21	89	15	242	29	3	17	72	29	14	13	BDL	BDL
TC3467	34	17	13	76	BDL	533	22	2	41	111	53	11	23	BDL	BDL
TC3470	44	23	27	96	BDL	298	29	6	25	93	40	7	29	BDL	BDL
TC3470DUP	17	29	29	94	BDL	350	28	5	34	102	38	7	25	BDL	BDL
TC3471	54	395	BDL	129	8	303	24	BDL	51	218	82	22	34	6	BDL
TC3473	166	84	47	119	BDL	1024	25	8	70	273	123	24	43	7	92
TC3474	40	24	25	149	7	291	31	BDL	20	70	26	18	15	BDL	BDL
TC3474DUP	28	34	31	169	BDL	363	38	5	33	96	31	21	21	BDL	BDL
TC3477	42	30	28	129	BDL	307	32	3	29	86	33	20	18	BDL	BDL
TC3478	54	69	13	298	BDL	880	34	4	93	348	102	25	30	BDL	24
TC3480	61	181	31	182	BDL	670	BDL	4	63	200	62	6	30	25	16
TC3481	52	20	19	135	BDL	231	30	4	18	65	26	15	16	BDL	BDL
TC3483	46	21	14	95	BDL	256	22	4	24	74	33	6	10	BDL	BDL
TC3484	30	20	25	BDL	BDL	226	20	3	21	61	34	7	17	BDL	BDL
TC3485	47	131	13	30	BDL	557	78	3	49	178	63	10	37	5	17
TC3486	55	34	31	153	BDL	329	21	5	115	511	167	9	49	BDL	14
TC3487	60	163	24	163	BDL	542	27	4	50	185	69	6	27	26	20
TC3488	24	17	16	39	BDL	150	11	3	17	61	27	10	12	BDL	BDL
TC3489	57	164	38	168	BDL	609	29	4	53	190	69	8	25	25	17
TC3490	57	64	22	162	13	491	49	5	55	230	81	7	33	5	17
TC3508	65	34	66	BDL	BDL	917	32	105	142	53	BDL	24	36	BDL	BDL
TC3511	50	30	37	46	BDL	511	31	6	28	28	37	8	20	BDL	BDL
TC3514	120	44	52	BDL	BDL	1016	180	8	92	263	132	31	53	14	36
TC3517	143	560	60	449	96	1700	137	11	366	1491	711	40	139	14	71
TC3520	81	45	52	BDL	28	946	59	9	67	175	78	24	35	BDL	BDL

PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TC3521	67	44	48	252	BDL	604	35	98	126	56	BDL	26	34	BDL	BDL
TC3524	48	44	24	80	BDL	370	28	5	36	129	49	7	29	BDL	15
TC3527	130	247	19	192	12	819	120	5	173	667	218	5	50	4	13
TC3530	40	32	27	58	BDL	463	29	3	29	87	37	23	21	BDL	BDL
TC3533	130	47	61	638	BDL	1516	39	9	295	1206	582	41	156	BDL	54
TC3641	76	36	45	132	BDL	1254	60	8	75	211	99	38	44	6	BDL
TC3642	130	103	52	152	BDL	1392	188	8	72	239	121	33	61	BDL	BDL
TC3644	375	43	48	213	40	1937	8174	11	82	213	107	31	47	20	42
TC3645	95	496	32	157	24	3309	63	5	109	336	125	25	48	10	56
TC3647	76	54	186	52	BDL	1075	60	9	31	180	98	32	35	BDL	BDL
TC3647DUP	37	74	79	170	53	2605	77	15	101	325	136	47	56	11	BDL
TC3648	39	33	31	BDL	9	613	33	5	39	103	35	6	20	4	BDL
TC3650	74	53	34	220	31	1186	38	BDL	72	245	104	32	44	BDL	BDL
TC3651	152	1103	59	191	25	1198	38	9	877	3594	1147	28	64	903	87
TC3653	75	49	47	157	36	1748	61	8	81	340	152	35	56	8	BDL
TC3654	55	1611	22	148	34	720	590	8	55	197	63	32	31	BDL	28
TC3657	132	241	BDL	121	15	566	36	4	36	112	34	21	19	BDL	27
TC3658	94	361	23	169	24	794	47	4	69	197	57	25	22	BDL	21
TC3660	50	23	21	176	11	472	56	3	55	202	70	26	26	BDL	BDL
TC3661	43	29	21	113	21	704	34	4	29	109	34	19	21	BDL	BDL
TC3663	63	57	32	168	BDL	489	46	5	32	103	40	BDL	26	BDL	26
TC3664	82	26	23	184	BDL	619	39	BDL	59	203	70	19	26	BDL	22
TC3666	55	28	24	210	19	940	75	5	99	385	145	24	48	BDL	BDL
TC3667	41	23	23	107	BDL	556	58	5	34	120	40	25	22	BDL	BDL
TC3669	273	47	28	214	24	626	84	5	96	390	141	25	85	BDL	43
TC3669DUP	309	66	29	237	19	803	112	7	121	480	164	30	104	6	45
TC3670	45	22	19	137	BDL	395	25	4	21	87	22	11	14	5	BDL
TC3670DUP	34	37	23	129	BDL	464	38	6	29	97	39	7	20	BDL	BDL
TC3957	65	35	24	165	21	1172	64	4	66	263	110	25	41	5	32
TC3958	31	21	19	66	BDL	372	10	3	18	50	18	10	11	BDL	BDL
TC3960	39	77	BDL	19	457	BDL	4	41	146	61	BDL	20	27	BDL	BDL
TC3961	51	43	19	89	BDL	430	40	4	35	130	72	11	26	10	37
TC3963	44	24	BDL	138	10	593	34	4	61	220	96	19	37	BDL	BDL

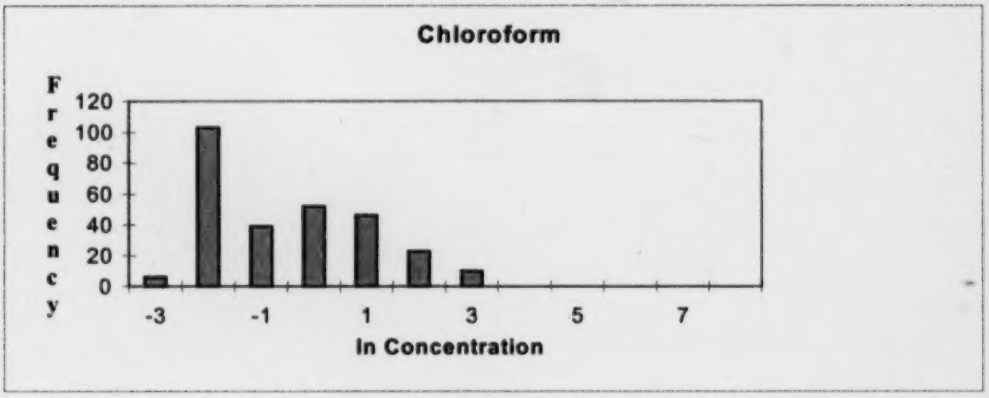
PSD ID	Volatile Organic Compound (ng/mL)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TC3964	28	23	8	67	BDL	319	41	4	19	50	35	8	19	0	BDL
TC3964DUP	20	27	25	96	16	513	40	5	23	74	41	12	20	BDL	BDL
TC3966	95	658	40	225	19	3945	68	6	126	395	141	27	60	9	59
TC3968	36	23	22	59	16	397	18	3	21	79	25	9	14	4	BDL
TC3970	82	487	29	219	15	2900	67	5	99	313	125	28	50	9	54
TC3971	44	24	15	67	20	435	37	3	24	91	49	11	28	17	27
TC4047	115	44	18	143	18	738	62	6	56	221	55	22	30	7	43
TC4048	29	25	17	66	BDL	351	22	BDL	29	92	34	10	14	3	BDL
TC4049	34	25	22	76	19	524	29	4	39	160	52	18	23	BDL	BDL
TC4049DUP	19	37	34	149	22	753	43	5	55	209	59	20	27	6	BDL
TC4050	63	57	22	153	BDL	522	38	4	83	307	82	31	25	43	31
TC4054	73	39	19	154	8	650	69	4	82	322	95	19	32	BDL	36
TC4057	30	30	21	65	11	454	19	6	47	167	52	BDL	21	6	BDL
TC4060	32	23	21	BDL	BDL	481	28	4	43	171	48	BDL	19	5	BDL
TC4061	99	22	26	64	BDL	470	30	4	33	108	73	11	149	BDL	20
TC4066	69	37	27	209	BDL	940	42	5	123	472	104	BDL	30	13	88
TK5869	39	17	22	119	30	410	BDL	11	17	67	20	9	8	6	BDL
TK5906	39	7	16	155	31	492	20	12	21	102	36	33	13	4	BDL
TK6076	61	42	24	211	22	485	BDL	12	56	241	84	32	20	49	25
TK6096	85	33	27	168	21	445	47	11	42	170	54	9	14	17	34
TK6102	48	21	24	153	13	389	BDL	14	48	186	80	27	22	BDL	BDL
TK6214	48	22	24	221	36	523	25	12	45	151	55	8	19	7	BDL
TK6233	38	17	22	145	25	444	23	15	21	110	41	7	15	9	BDL
TK6242	233	51	32	216	23	578	BDL	11	95	338	93	31	26	26	95
TK6248	43	20	23	186	27	337	10	15	27	141	54	12	15	10	BDL
TK6257	39	17	18	167	27	426	23	15	52	194	70	11	22	7	BDL
TK6257DUP	27	26	24	258	28	515	35	17	56	229	90	9	28	11	BDL
TK6345	54	170	27	149	14	671	124	13	82	330	98	12	28	9	32
TK6396	80	17	24	224	11	580	43	14	65	249	84	34	33	13	65
TU2567	130	1471	24	116	23	475	30	6	155	658	253	10	107	10	48
TU2609	63	103	18	80	BDL	412	73	6	44	132	63	14	20	6	25

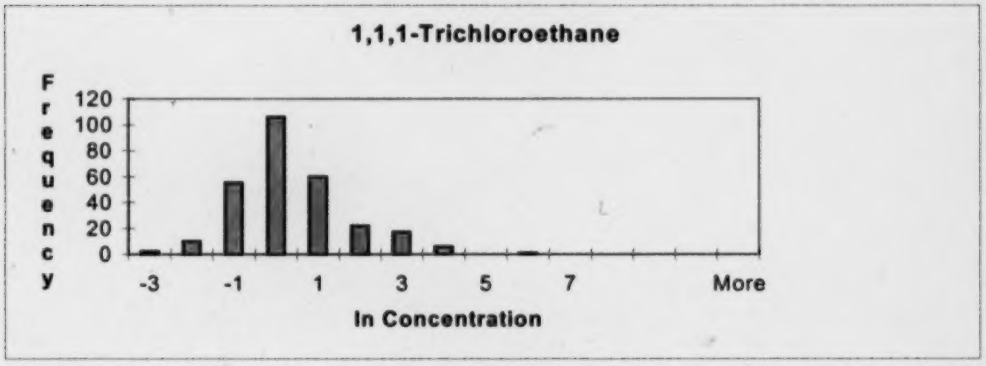
Appendix 25: Calculation Constants for the Determination of Ambient VOC Concentrations.

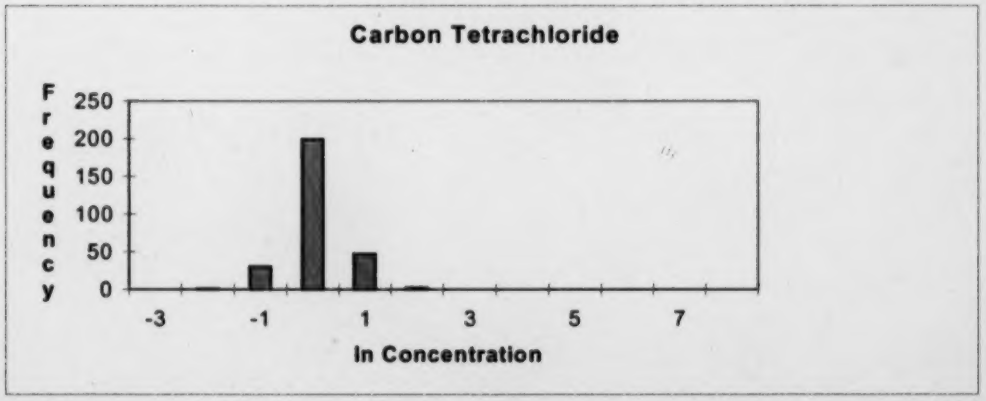
Volatile Organic Compounds	Calculation Constant (A)	Recovery Coefficient (r)	Ctb (ng/mL)
chloroform	29.9	0.95	35
1,1,1-trichloroethane	32.4	1.00	10
carbon tetrachloride	33.1	0.95	4.9
benzene	28.2	0.97	69
trichloroethylene	32.2	1.01	13
toluene	31.8	1.00	310
tetrachloroethylene	35.3	1.03	14
chlorobenzene	34.1	0.96	6.1
ethylbenzene	36.6	0.96	15
(m+p) xylene	36.6	0.97	49
o-xylene	36.6	0.97	19
napthalene	40.7	0.42	12
1,3,5-trimethylbenzene	38.0	1.05	9.3
1,4-dichlorobenzene	36.0	0.74	3.6
styrene	34.6	0.88	8.8

Ctb = Concentration of trip blank.

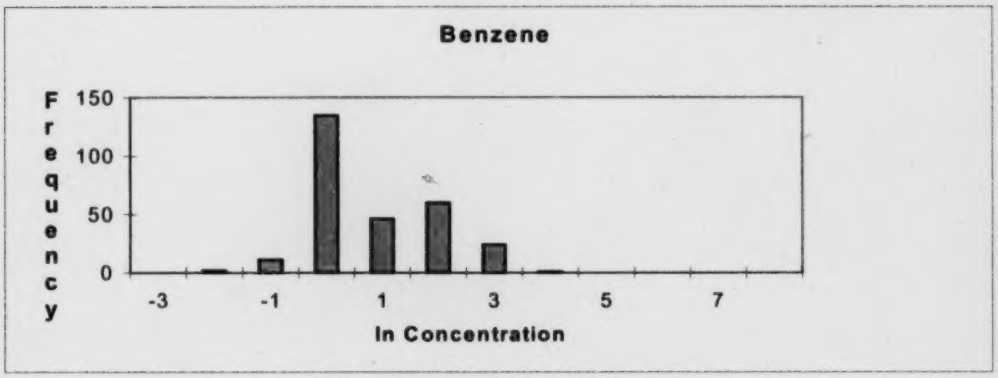
Appendix 26.1: Data Distributions for Target Compounds.

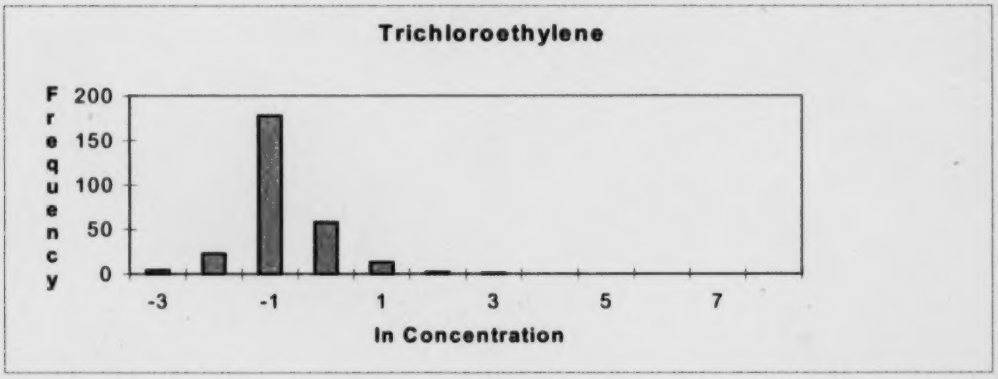


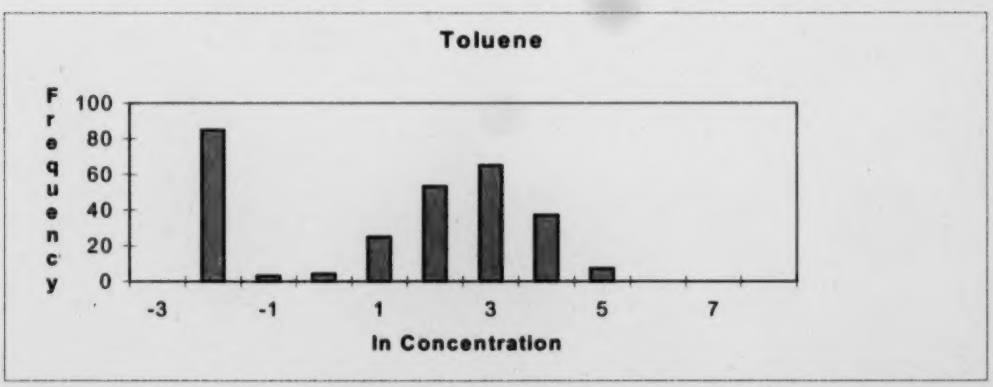




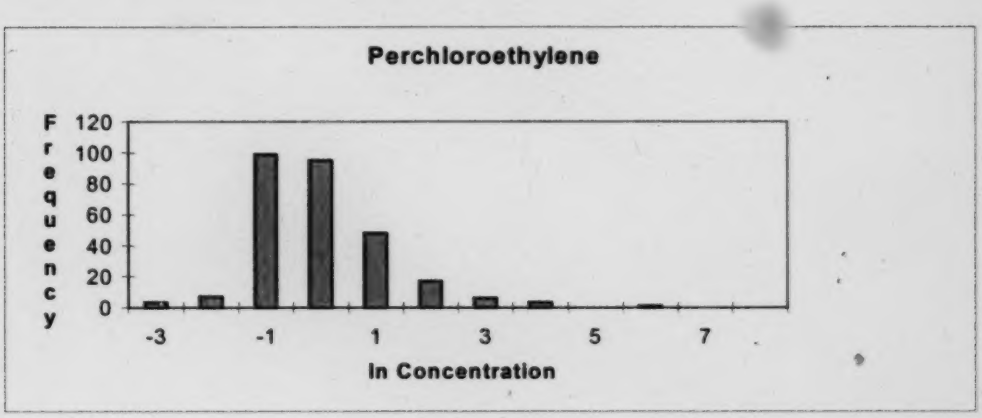
Appendix 26.2: Data Distributions for Target Compounds.

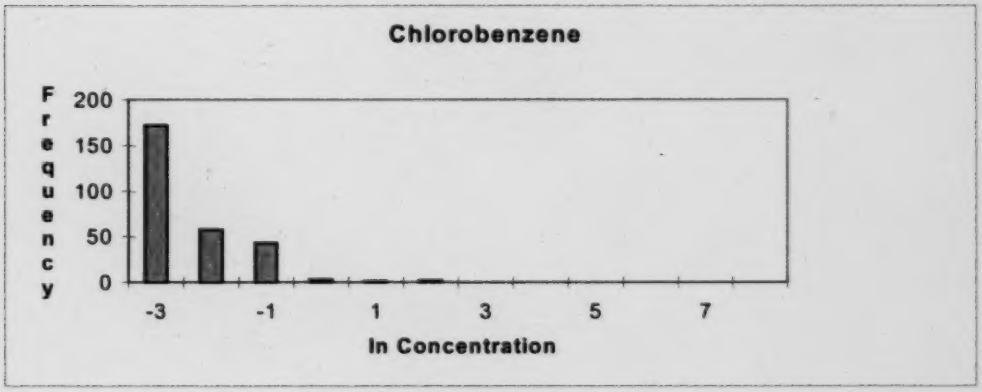


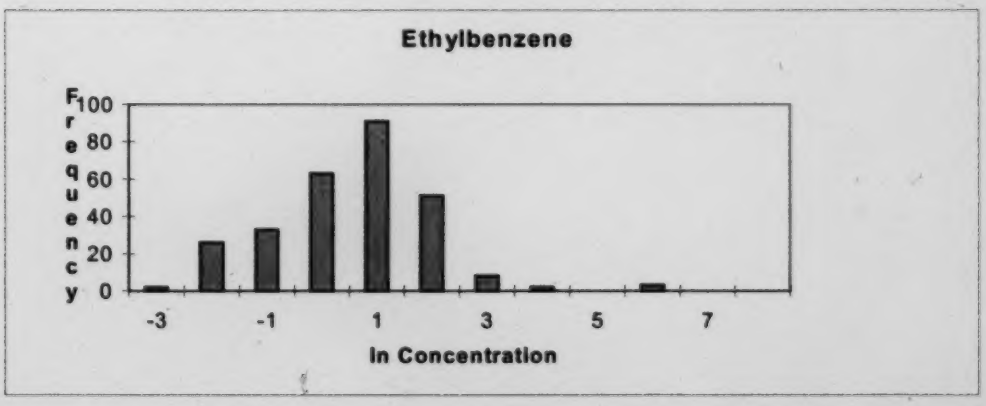




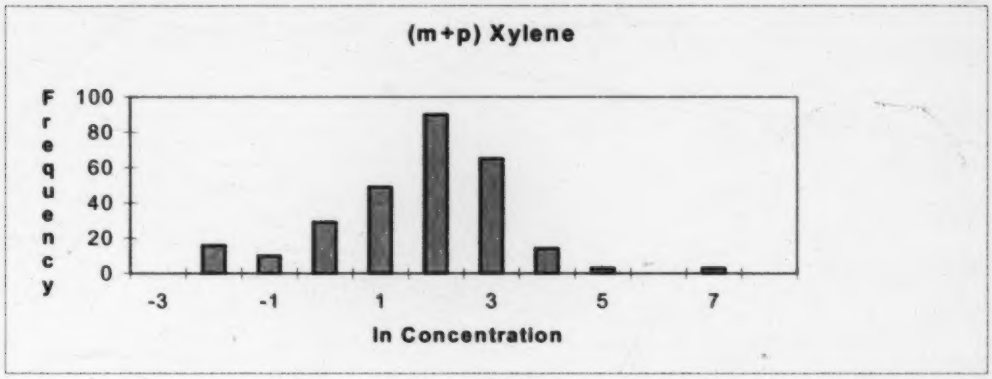
Appendix 26.3: Data Distributions for Target Compounds.

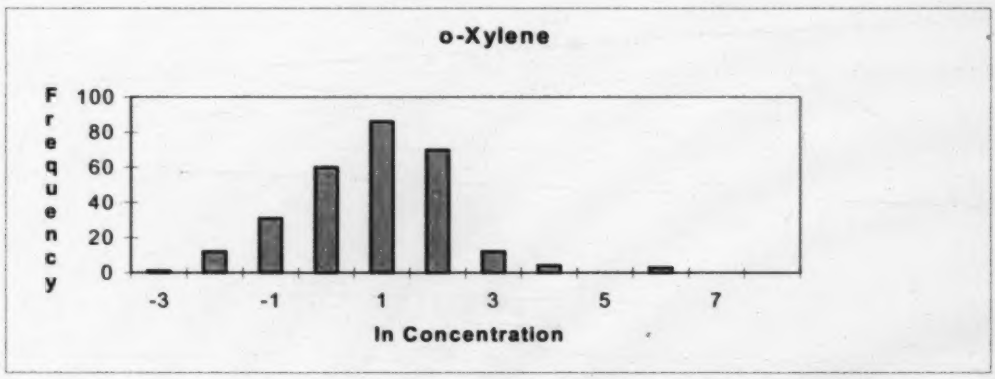


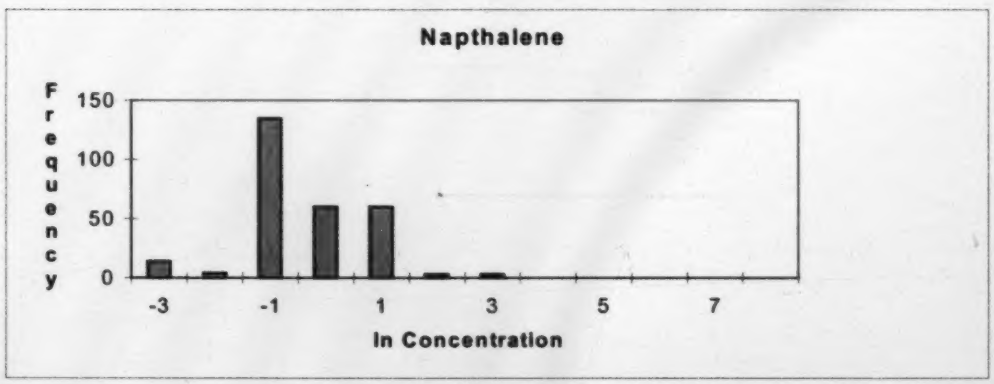




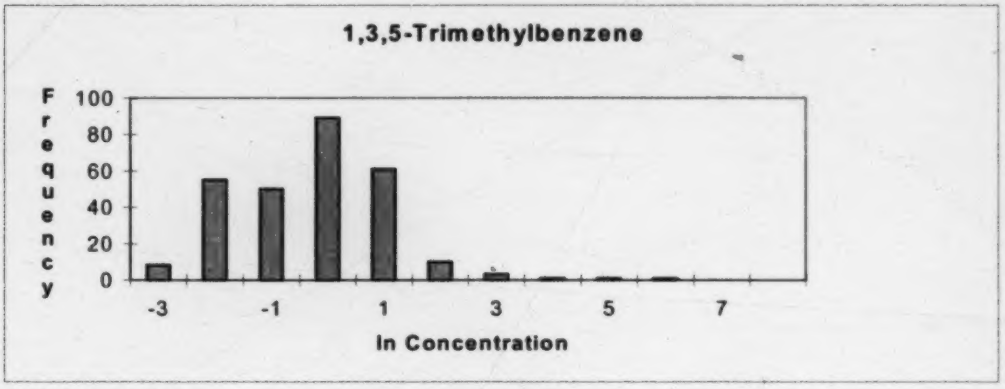
Appendix 26.4: Data Distributions for Target Compounds.

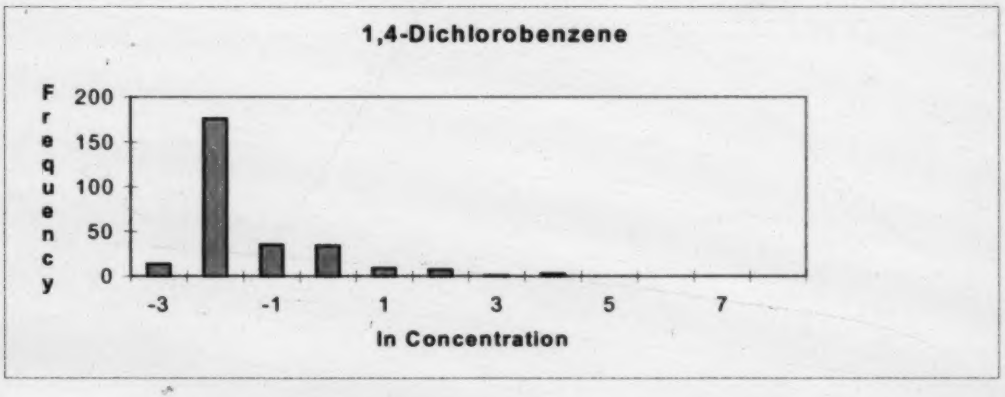


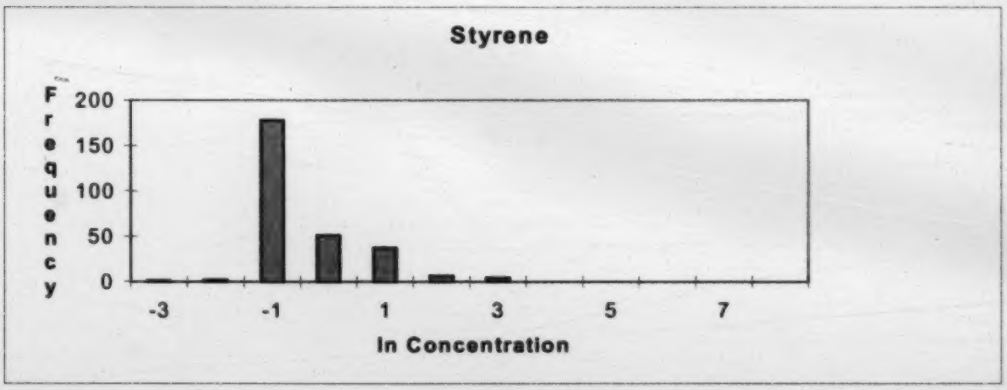




Appendix 26.5: Data Distributions for Target Compounds.







Appendix 27.1: Statistical Tests for Indoor-Outdoor Differences.

t-Test: Paired Two Sample for Means
Hypothesized mean difference of zero.
$\alpha = 0.05$

Comparison of VOC Levels in the Fall Season:

Statistical Measure	Chloroform		1,1,1-Trichloroethane		Carbon Tetrachloride		Benzene	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Mean	-0.3	-1.8	0.5	-1.0	-0.4	-0.4	0.5	0.3
Variance	1.7	0.8	1.9	0.7	0.2	0.2	1.7	1.2
Observations	64	64	64	64	64	64	64	64
Hypothesized Mean Difference	0		0		0		0	
df	63		63		63		63	
t Stat	5.6		7.9		0.1		2.1	
P(T<=t) one-tail	0.0		0.0		0.5		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.9		0.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of VOC Levels in the Winter Season:

Statistical Measure	Chloroform		1,1,1-Trichloroethane		Carbon Tetrachloride		Benzene	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Mean	0.2	-1.6	0.6	-0.8	-0.4	-0.5	0.6	0.0
Variance	1.1	0.7	1.6	0.3	0.3	0.4	0.8	0.6
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	15.7		8.4		1.3		6.1	
P(T<=t) one-tail	0.0		0.0		0.1		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.2		0.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of VOC Levels in the Fall Season:

Statistical Measure	Trichloroethylene		Toluene		Perchloroethylene		Chlorobenzene	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Mean	-1.2	-1.3	1.6	-0.7	-0.1	-1.0	-2.6	-2.7
Variance	0.7	0.6	3.8	4.8	2.2	0.9	0.7	0.5
Observations	64	64	64	64	64	64	64	64
Hypothesized Mean Difference	0		0		0		0	
df	63		63		63		63	
t Stat	1.0		8.3		4.7		-0.1	
P(T<=t) one-tail	0.2		0.0		0.0		0.5	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.3		0.0		0.0		0.9	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of VOC Levels in the Winter Season:

Statistical Measure	Trichloroethylene		Toluene		Perchloroethylene		Chlorobenzene	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Mean	-1.5	-1.5	1.9	-0.1	0.1	-1.0	-2.9	-2.6
Variance	0.6	0.6	2.3	4.6	1.6	0.5	0.4	1.0
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	0.2		8.0		7.0		-2.2	
P(T<=t) one-tail	0.4		0.0		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.9		0.0		0.0		0.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Appendix 27.2: Statistical Tests for Indoor-Outdoor Differences.

t-Test: Paired Two Sample for Means
Hypothesized mean difference of zero.
$\alpha = 0.05$

Comparison of VOC Levels in the Fall Season:

Statistical Measure	Ethylbenzene		(m+p)-Xylene		o-Xylene		Napthalene	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Mean	0.9	-0.7	2.2	0.6	1.1	-0.3	-0.8	-1.4
Variance	1.3	1.6	1.3	1.8	1.2	1.3	1.0	0.7
Observations	64	64	64	64	64	64	64	64
Hypothesized Mean Difference	0		0		0		0	
df	63		63		63		63	
t Stat	9.6		8.3		8.8		4.5	
P(T<=t) one-tail	0.0		0.0		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.0		0.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of VOC Levels in the Winter Season:

Statistical Measure	Ethylbenzene		(m+p)-Xylene		o-Xylene		Napthalene	
	In	*Out*	*In*	*Out*	*In*	*Out*	*In*	*Out*
Mean	0.6	-0.7	1.8	0.2	0.9	-0.5	-0.7	-1.1
Variance	0.8	1.2	1.2	1.9	0.8	1.2	1.4	1.0
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	9.5		8.6		9.0		2.7	
P(T<=t) one-tail	0.0		0.0		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.0		0.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of VOC Levels in the Fall Season:

Statistical Measure	1,3,5-Trimethylbenzene		1,4-Dichlorobenzene		Styrene	
	In	*Out*	*In*	*Out*	*In*	*Out*
Mean	-0.3	-1.6	-1.3	-2.0	-0.7	-1.4
Variance	1.8	1.5	1.7	0.7	1.0	0.3
Observations	64	64	64	64	64	64
Hypothesized Mean Difference	0		0		0	
df	63		63		63	
t Stat	7.4		3.6		5.5	
P(T<=t) one-tail	0.0		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.0	
t Critical two-tail	2.0		2.0		2.0	

Comparison of VOC Levels in the Winter Season:

Statistical Measure	1,3,5-Trimethylbenzene		1,4-Dichlorobenzene		Styrene	
	In	*Out*	*In*	*Out*	*In*	*Out*
Mean	-0.1	-1.2	-1.6	-2.3	-0.2	-1.6
Variance	0.7	0.9	1.6	0.3	0.8	0.0
Observations	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0	
df	61		61		61	
t Stat	7.9		3.4		12.1	
P(T<=t) one-tail	0.0		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.0	
t Critical two-tail	2.0		2.0		2.0	

Appendix 28.1: Statistical Tests for Fall- Winter Differences.

t-Test: Paired Two Sample for Means
Hypothesized mean difference of zero.
$\alpha = 0.05$

Comparison of Indoor VOC Levels:

Statistical Measure	Chloroform		1,1,1-Trichloroethane		Carbon Tetrachloride		Benzene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-0.3	0.2	0.5	0.6	-0.4	-0.4	0.5	0.6
Variance	1.7	1.1	2.0	1.6	0.3	0.3	1.8	0.8
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	-2.2		-1.0		0.6		-0.3	
P(T<=t) one-tail	0.0		0.2		0.3		0.4	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.3		0.6		0.8	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	Chloroform		1,1,1-Trichloroethane		Carbon Tetrachloride		Benzene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-1.8	-1.6	-1.0	-0.8	-0.4	-0.5	0.3	0.0
Variance	0.8	0.7	0.7	0.3	0.2	0.4	1.2	0.6
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	-0.8		-1.2		1.6		1.7	
P(T<=t) one-tail	0.2		0.1		0.1		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.5		0.2		0.1		0.1	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Indoor VOC Levels:

Statistical Measure	Trichloroethylene		Toluene		Perchloroethylene		Chlorobenzene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-1.1	-1.5	1.7	1.9	-0.1	0.1	-2.6	-2.9
Variance	0.7	0.6	3.8	2.3	2.2	1.6	0.7	0.4
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	2.8		-0.7		-1.1		1.7	
P(T<=t) one-tail	0.0		0.2		0.1		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.5		0.3		0.1	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	Trichloroethylene		Toluene		Perchloroethylene		Chlorobenzene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-1.3	-1.5	-0.7	-0.1	-0.9	-1.0	-2.6	-2.6
Variance	0.6	0.6	4.9	4.6	0.9	0.5	0.5	1.0
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	1.3		-1.6		0.2		-0.2	
P(T<=t) one-tail	0.1		0.1		0.4		0.4	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.2		0.1		0.9		0.9	
t Critical two-tail	2.0		2.0		2.0		2.0	

Appendix 28.2: Statistical Tests for Fall- Winter Differences.

t-Test: Paired Two Sample for Means
Hypothesized mean difference of zero.
$\alpha = 0.05$

Comparison of Indoor VOC Levels:

Statistical Measure	Ethylbenzene		(m+p)-Xylene		o-Xylene		Napthalene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	1.0	0.6	2.2	1.8	1.1	0.9	-0.8	-0.7
Variance	1.3	0.8	1.3	1.2	1.2	0.8	1.1	1.4
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	2.7		2.5		1.3		-0.5	
P(T<=t) one-tail	0.0		0.0		0.1		0.3	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.2		0.6	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	Ethylbenzene		(m+p)-Xylene		o-Xylene		Napthalene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-0.7	-0.7	0.6	0.2	-0.3	-0.5	-1.4	-1.1
Variance	1.5	1.2	1.8	1.9	1.3	1.2	0.7	1.0
Observations	62	62	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0		0	
df	61		61		61		61	
t Stat	0.0		2.0		1.1		-1.9	
P(T<=t) one-tail	0.5		0.0		0.1		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	1.0		0.0		0.3		0.1	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Indoor VOC Levels:

Statistical Measure	1,3,5-Trimethylbenzene		1,4-Dichlorobenzene		Styrene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-0.3	-0.1	-1.3	-1.6	-0.7	-0.2
Variance	1.9	0.7	1.8	1.6	1.0	0.8
Observations	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0	
df	61		61		61	
t Stat	-1.3		2.6		-2.8	
P(T<=t) one-tail	0.1		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7	
P(T<=t) two-tail	0.2		0.0		0.0	
t Critical two-tail	2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	1,3,5-Trimethylbenzene		1,4-Dichlorobenzene		Styrene	
	Fall	*Winter*	*Fall*	*Winter*	*Fall*	*Winter*
Mean	-1.6	-1.2	-2.0	-2.3	-1.4	-1.6
Variance	1.4	0.9	0.7	0.3	0.3	0.0
Observations	62	62	62	62	62	62
Hypothesized Mean Difference	0		0		0	
df	61		61		61	
t Stat	-2.0		1.8		2.9	
P(T<=t) one-tail	0.0		0.0		0.0	
t Critical one-tail	1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.1		0.0	
t Critical two-tail	2.0		2.0		2.0	

Appendix 29: Statistical Tests of Variance Between St. Albert and Sherwood Park.

F-Test: Two tailed test for equal variances.
Hypothesized equal variances.
$\alpha = 0.05$
F-critical = F(60, 64, 0.05) = 1.52

Comparison of Indoor VOC Variance:

	Variance		F-Test		Variance Test	
Volatile Organic Compound	St.Albert	Sh. Park	F-statistic	F-critical	Equal	Unequal
Chloroform	1.4	1.5	1.1	1.5	X	
1,1,1-Trichloroethane	2.3	1.3	1.8	1.5		X
Carbon Tetrachloride	0.3	0.3	1.0	1.5	X	
Benzene	1.4	1.3	1.1	1.5	X	
Trichloroethylene	0.9	0.5	1.8	1.5		X
Toluene	3.4	2.8	1.2	1.5	X	
Tetrachloroethylene	1.9	2.0	1.1	1.5	X	
Chlorobenzene	0.5	0.6	1.2	1.5	X	
Ethylbenzene	1.0	1.2	1.2	1.5	X	
(m+p) xylene	1.0	1.5	1.5	1.5	X	
o-xylene	1.0	1.0	1.0	1.5	X	
Naphthalene	1.7	0.8	2.1	1.5		X
1,3,5-Trimethylbenzene	1.4	1.2	1.2	1.5	X	
1,4-Dichlorobenzene	1.6	1.8	1.1	1.5	X	
Styrene	1.0	0.9	1.1	1.5	X	

Comparison of Outdoor VOC Variance:

	Variance		F-Test		Variance Test	
Volatile Organic Compound	St.Albert	Sh. Park	F-statistic	F-critical	Equal	Unequal
Chloroform	0.6	0.9	1.5	1.5	X	
1,1,1-Trichloroethane	0.5	0.5	1.0	1.5	X	
Carbon Tetrachloride	0.2	0.3	1.5	1.5	X	
Benzene	1.0	0.7	1.4	1.5	X	
Trichloroethylene	0.8	0.4	2.0	1.5		X
Toluene	5.0	4.2	1.2	1.5	X	
Tetrachloroethylene	0.6	0.8	1.3	1.5	X	
Chlorobenzene	1.0	0.5	2.0	1.5		X
Ethylbenzene	1.3	1.2	1.1	1.5	X	
(m+p) xylene	1.9	1.7	1.1	1.5	X	
o-xylene	1.3	1.0	1.3	1.5	X	
Naphthalene	1.1	0.6	2.2	1.5		X
1,3,5-Trimethylbenzene	1.0	1.2	1.2	1.5	X	
1,4-Dichlorobenzene	0.4	0.5	1.3	1.5	X	
Styrene	0.0	0.3	8.6	1.5		X

Appendix 30.1: Statistical Tests for St. Albert-Sherwood Park Differences.

t-Test: Two Sample for Means
Hypothesized mean difference of zero.
$\alpha = 0.05$

Comparison of Indoor VOC Levels:

Statistical Measure	Chloroform		1,1,1-Trichloroethane		Carbon Tetrachloride		Benzene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	0.2	-0.2	0.6	0.6	-0.3	-0.4	0.6	0.6
Variance	1.4	1.5	2.3	1.3	0.3	0.3	1.4	1.3
Observations	60	64	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0		0	
df	122		110		122		122	
t Stat	1.9		-0.1		1.1		0.1	
P(T<=t) one-tail	0.0		0.5		0.1		0.5	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.1		1.0		0.3		0.9	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	Chloroform		1,1,1-Trichloroethane		Carbon Tetrachloride		Benzene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	-1.7	-1.7	-0.8	-0.9	-0.4	-0.5	0.4	-0.1
Variance	0.6	0.9	0.5	0.5	0.2	0.3	1.0	0.7
Observations	60	64	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0		0	
df	120		122		120		115	
t Stat	0.5		0.8		0.5		2.8	
P(T<=t) one-tail	0.3		0.2		0.3		0.0	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.6		0.5		0.6		0.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Indoor VOC Levels:

Statistical Measure	Trichloroethylene		Toluene		Perchloroethylene		Chlorobenzene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	-1.4	-1.3	1.7	1.9	0.1	0.0	-2.7	-2.8
Variance	0.9	0.5	3.4	2.8	1.9	2.0	0.5	0.6
Observations	60	64	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0		0	
df	122		122		122		122	
t Stat	-0.6		-0.7		0.5		0.3	
P(T<=t) one-tail	0.3		0.3		0.3		0.4	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.6		0.5		0.6		0.8	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	Trichloroethylene		Toluene		Perchloroethylene		Chlorobenzene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	-1.3	-1.5	0.1	-0.8	-0.8	-1.1	-2.6	-2.7
Variance	0.8	0.4	5.0	4.2	0.6	0.8	1.0	0.5
Observations	60	64	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0		0	
df	106		119		120		122	
t Stat	1.2		2.3		1.5		0.8	
P(T<=t) one-tail	0.1		0.0		0.1		0.2	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.2		0.0		0.1		0.4	
t Critical two-tail	2.0		2.0		2.0		2.0	

Appendix 30.2: Statistical Tests for St. Albert-Sherwood Park Differences.

t-Test: Two Sample for Means
Hypothesized mean difference of zero.
$\alpha = 0.05$

Comparison of Indoor VOC Levels:

Statistical Measure	Ethylbenzene		(m+p)-Xylene		o-Xylene		Napthalene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	0.8	0.7	2.1	1.9	1.1	0.9	-0.7	-0.8
Variance	1.0	1.2	1.0	1.5	1.0	1.0	1.7	0.8
Observations	60	64	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0		0	
df	122		120		121		105	
t Stat	0.7		1.1		1.0		0.2	
P(T<=t) one-tail	0.3		0.1		0.2		0.4	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.5		0.3		0.3		0.8	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	Ethylbenzene		(m+p)-Xylene		o-Xylene		Napthalene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	-0.3	-1.0	0.7	0.1	-0.1	-0.7	-1.2	-1.2
Variance	1.3	1.2	1.9	1.7	1.3	1.0	1.1	0.6
Observations	60	64	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0		0	
df	120		121		118		122	
t Stat	3.5		2.7		3.1		0.0	
P(T<=t) one-tail	0.0		0.0		0.0		0.5	
t Critical one-tail	1.7		1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.0		0.0		1.0	
t Critical two-tail	2.0		2.0		2.0		2.0	

Comparison of Indoor VOC Levels:

Statistical Measure	1,3,5-Trimethylbenzene		1,4-Dichlorobenzene		Styrene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	0.0	-0.4	-1.5	-1.5	-0.4	-0.5
Variance	1.4	1.2	1.6	1.8	1.0	0.9
Observations	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0	
df	120		122		120	
t Stat	1.8		-0.2		0.9	
P(T<=t) one-tail	0.0		0.4		0.2	
t Critical one-tail	1.7		1.7		1.7	
P(T<=t) two-tail	0.1		0.8		0.4	
t Critical two-tail	2.0		2.0		2.0	

Comparison of Outdoor VOC Levels:

Statistical Measure	1,3,5-Trimethylbenzene		1,4-Dichlorobenzene		Styrene	
	St. Albert	*Sh. Park*	*St. Albert*	*Sh. Park*	*St. Albert*	*Sh. Park*
Mean	-1.1	-1.7	-2.0	-2.2	-1.6	-1.5
Variance	1.0	1.2	0.4	0.5	0.0	0.3
Observations	60	64	60	64	60	64
Hypothesized Mean Difference	0		0		0	
df	122		122		80	
t Stat	3.1		1.4		-1.5	
P(T<=t) one-tail	0.0		0.1		0.1	
t Critical one-tail	1.7		1.7		1.7	
P(T<=t) two-tail	0.0		0.2		0.1	
t Critical two-tail	2.0		2.0		2.0	

Appendix 31: Summary of PSD Trip Blanks (n = 12).

Volatile Organic Compounds	Concentration (ng/mL)				BDL[1] (%)
	Mean	σ	Minimum	Maximum	
Chloroform	35	9.3	18	46	0
1,1,1-Trichloroethane	10	6.5	3.3	21	33
Carbon Tetrachloride	4.9	0.0	4.9	4.9	100
Benzene	69	94	21	310	75
Trichloroethylene	13	11	5.6	37	58
Toluene	310	170	85	600	0
Tetrachloroethylene	14	10	7.1	33	58
Chlorobenzene	6.1	4.2	1.3	16	8
Ethylbenzene	15	7.2	6.0	27	0
(m+p) xylene	49	26	18	97	0
o-xylene	19	11	4.2	48	8
Naphthalene	12	7.5	1.8	29	17
1,3,5-Trimethylbenzene	9.3	6.4	3.0	19	42
1,4-Dichlorobenzene	3.6	2.8	2.2	11	75
Styrene	8.8	7.9	4.8	28	67

Volatile Organic Compounds	Concentration ($\mu g/m^3$)				BDL[1] (%)
	Mean	σ	Minimum	Maximum	
Chloroform	1.2	0.3	0.6	1.5	0
1,1,1-Trichloroethane	0.3	0.2	0.1	0.7	33
Carbon Tetrachloride	0.2	0.0	0.2	0.2	100
Benzene	2.1	2.9	0.6	9.3	75
Trichloroethylene	0.4	0.4	0.2	1.2	58
Toluene	10	5.7	2.8	20	0
Tetrachloroethylene	0.5	0.4	0.3	1.2	58
Chlorobenzene	0.2	0.2	0.0	0.6	8
Ethylbenzene	0.6	0.3	0.2	1.1	0
(m+p) xylene	1.9	1.0	0.7	3.8	0
o-xylene	0.7	0.4	0.2	1.9	8
Naphthalene	1.2	0.8	0.2	2.9	17
1,3,5-Trimethylbenzene	0.4	0.2	0.1	0.7	42
1,4-Dichlorobenzene	0.2	0.1	0.1	0.6	75
Styrene	0.4	0.3	0.2	1.1	67

1. This represents the percentage of trip blanks reported as BDL by the analytical lab.
σ = standard deviation

Appendix 32: Summary of Indoor Sampling Precision (RSD, %).

	Volatile Organic Compound				
Replicate Set	Chloroform	1,1,1-Trichloroethane	Carbon Tetrachloride	Benzene	Trichloroethylene
1	10	28	27	17	1
2	17	9	13	12	70
3	130	18	28	0	51
4	38	25	88	0	53
5	14	18	20	29	74
6	42	20	17	53	0
7	9	6	26	10	0
Mean	37	18	31	17	35
Median	17	18	26	12	51
Minimum	9	6	13	0	0
Maximum	130	28	88	53	74

	Volatile Organic Compound				
Replicate Set	Toluene	Tetrachloroethylene	Chlorobenzene	Ethylbenzene	(m+p) xylene
1	26	11	110	10	10
2	48	12	81	19	16
3	20	23	46	6	10
4	28	61	0	25	10
5	17	5	0	14	14
6	53	54	0	20	19
7	22	35	0	17	5
Mean	31	29	34	16	12
Median	26	23	0	17	10
Minimum	17	5	0	6	5
Maximum	53	61	110	25	19

	Volatile Organic Compound				
Replicate Set	o-xylene	Naphthalene	1,3,5-Trimethylbenzene	1,4-Dichlorobenzene	Styrene
1	11	20	76	16	8
2	17	94	31	11	35
3	4	14	10	35	40
4	7	0	64	0	0
5	8	10	15	11	6
6	15	79	33	16	30
7	8	0	14	2	23
Mean	10	31	35	13	20
Median	8	14	31	11	23
Minimum	4	0	10	0	0
Maximum	17	94	76	35	40

Appendix 33: Summary of Outdoor Sampling Precision (RSD, %).

Replicate Set	Volatile Organic Compound				
	Chloroform	1,1,1-Trichloroethane	Carbon Tetrachloride	Benzene	Trichloroethylene
1	1.5	49	19	37	72
2	0	90	63	27	93
3	63	35	12	69	0
4	13	52	26	56	33
5	61	52	33	70	57
6	69	64	42	96	1.2
Mean	35	57	33	59	43
Median	37	52	30	62	45
Minimum	0	35	12	27	0
Maximum	69	90	63	96	93

Replicate Set	Volatile Organic Compound				
	Toluene	Tetrachloroethylene	Chlorobenzene	Ethylbenzene	(m+p) xylene
1	0	77	23	48	44
2	160	4.5	0.7	89	48
3	74	57	76	38	56
4	230	32	0.5	97	66
5	94	59	20	67	70
6	200	64	0.5	120	99
Mean	126	49	20	77	64
Median	127	58	10	78	61
Minimum	0	4	0	38	44
Maximum	230	77	76	120	99

Replicate Set	Volatile Organic Compound				
	o-xylene	Naphthalene	1,3,5-Trimethylbenzene	1,4-Dichlorobenzene	Styrene
1	52	0.4	27	77	0
2	11	16	86	62	0
3	61	110	54	81	0
4	90	130	200	0.3	0
5	70	77	40	45	0
6	98	87	73	0	0
Mean	64	70	80	44	0
Median	66	82	63	54	0
Minimum	11	0	27	0	0
Maximum	98	130	200	81	0

Appendix 34: Summary of Carbon Disulfide Laboratory Blanks (n = 29).

Volatile Organic Compounds	BDL[1] (%)	Mean Concentration (µg/m³)		Removal[2] (%)
		High Grade	Cleaned High Grade	
Chloroform	14	3.2	1.3	59
1,1,1-Trichloroethane	100	BDL	BDL	---
Carbon Tetrachloride	100	BDL	BDL	---
Benzene	62	23	3.3	86
Trichloroethylene	100	BDL	BDL	---
Toluene	100	BDL	BDL	---
Tetrachloroethylene	100	BDL	BDL	---
Chlorobenzene	100	BDL	BDL	---
Ethylbenzene	100	BDL	BDL	---
(m+p) xylene	100	BDL	BDL	---
o-xylene	100	BDL	BDL	---
Naphthalene	76	7.0	3.6	49
1,3,5-Trimethylbenzene	100	BDL	BDL	---
1,4-Dichlorobenzene	100	BDL	BDL	---
Styrene	100	BDL	BDL	---

1. This represents the percentage of laboratory blanks that were reported as BDL by the analytical laboratory.
2. This represents the percentage of background contamination in the high grade carbon disulfide that was removed by the cleaning procedure.

Appendix 35: Summary of the Desorption Efficiency Test Results.

Volatile Organic Compounds	Recovery (%)							RSD (%)
	r1	r3	r5	r7	Mean	σ	3M(1998a)	
Chloroform	170	190	180	170	180	10	95	5
1,1,1-Trichloroethane	200	210	220	190	210	13	95	6
Carbon Tetrachloride	230	240	240	190	220	24	95	11
Benzene	220	230	230	210	220	10	97	4
Trichloroethylene	200	200	200	190	200	5	101	3
Toluene	400	280	250	230	290	76	100	26
Tetrachloroethylene	170	210	180	170	180	19	103	11
Chlorobenzene	180	190	170	140	170	22	96	13
Ethylbenzene	240	280	220	190	230	38	96	16
(m+p) xylene	300	280	220	210	250	44	97	18
o-xylene	200	210	170	140	180	32	97	18
Naphthalene	23	60	35	32	37	16	42	43
1,3,5-Trimethylbenzene	180	200	170	140	170	25	105	15
1,4-Dichlorobenzene	---	---	---	---	---	---	74	---
Styrene	140	160	140	90	130	30	88	23

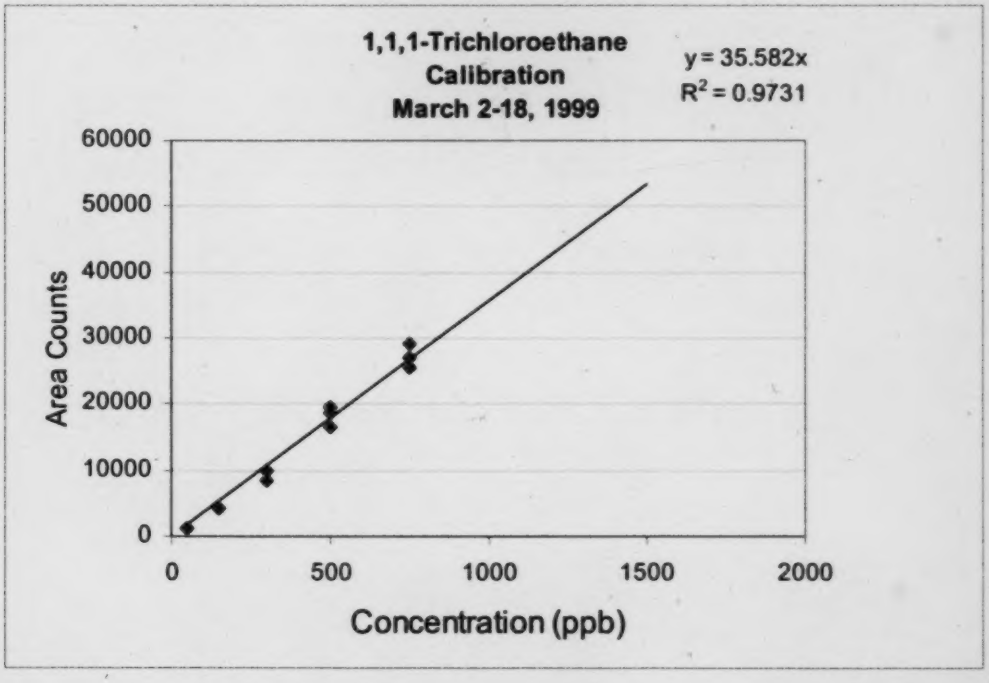
σ = standard deviation
RSD = relative standard deviation

Appendix 36: Summary of the Analytical Sensitivity (n = 7).

Volatile Organic Compounds	MDL (ng/mL)	LOQ (ng/mL)	MDL ($\mu g/m^3$)	LOQ ($\mu g/m^3$)
Chloroform	7.7	26	0.3	0.9
1,1,1-Trichloroethane	6.6	22	0.2	0.7
Carbon Tetrachloride	9.8	33	0.4	1.2
Benzene	41	140	1.3	4.2
Trichloroethylene	11	37	0.4	1.2
Toluene	5.5	18	0.2	0.6
Tetrachloroethylene	14	47	0.5	1.7
Chlorobenzene	2.7	9	0.1	0.3
Ethylbenzene	5.2	17	0.2	0.7
(m+p) xylene	6.0	20	0.2	0.8
o-xylene	8.5	28	0.3	1.1
Naphthalene	3.6	12	0.4	1.2
1,3,5-Trimethylbenzene	5.9	20	0.2	0.8
1,4-Dichlorobenzene	4.4	15	0.2	0.8
Styrene	9.6	32	0.4	1.3
Mean	9.5	32	0.3	1.2
Minimum	2.7	9.0	0.1	0.3
Maximum	41	140	1.3	4.2

MDL = method detection limit
LOQ = limit of quantitation

Appendix 37: Calibration Curve for 1,1,1-Trichloroethane.



Appendix 38: Summary of the Analytical Precision (n = 22).

Volatile Organic Compounds	Precision (RPD, %)			
	Median	Mean	Minimum	Maximum
Chloroform	21	39	0	180
1,1,1-Trichloroethane	40	46	6	110
Carbon Tetrachloride	25	39	4	150
Benzene	52	57	0	170
Trichloroethylene	24	38	0	150
Toluene	68	91	0	200
Tetrachloroethylene	32	38	0	130
Chlorobenzene	0	16	0	130
Ethylbenzene	43	54	0	160
(m+p) xylene	30	54	0	180
o-xylene	21	33	0	150
Naphthalene	46	64	0	180
1,3,5-Trimethylbenzene	33	32	0	78
1,4-Dichlorobenzene	2	23	0	130
Styrene	0	5	0	60

RPD = relative percent difference